Application of Freeway Simulation Models to Urban Corridors

Volume I: Final Report

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16. Abstract

Freeway simulation is gaining increasing acceptance and popularity as a toll for evaluating freeway improvement alternatives and refining freeway designs. The evaluation of individual sections one at a time is frequently inadequate to fully consider the implications of traffic flow on freeway design and operations. As the need to evaluate the interaction among sections and facilities increases, so too will the need to employ these more sophisticated analytical techniques. Several freeway simulation models now operate on microcomputers, simplifying the use of the models and opening up opportunities to may engineers previously unable to take advantage of the analysis power these models afford. The purpose of this research contract, entitled "Analysis of Complex Congested Corridor Locations," was to apply three freeway simulation models and the procedures in the *1985 Highway Capacity Manual* to real-world situations. Each of the models was applied in five case study sites: Seattle; Minneapolis; Milwaukee; Columbus, Ohio; and New York City. The application of the models provided the opportunity to compare their strengths and weakness, to suggest possible enhancements to the models evaluated included: FREFLO, a macroscopic simulation model developed under Federal Highway Administration contract; FREQ, a macroscopic model developed by the University of California at Berkeley; and FRESIM, a microscopic model developed under FHWA contract. This report is directed toward existing and potential users of freeway simulation models, with an emphasis on guidelines for model selection and application.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in2	square inches	645.2	square millimeters	mm2
ft2	square feet	0.093	square meters	m2
yd2	square yards	0.836	square meters	m2
ac	acres	0.405	hectares	ha
mi2	square miles	2.59	square kilometers	km2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft3	cubic feet	0.028	cubic meters	m3
yd3	cubic yards	0.765	cubic meters	m3
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons(200 lb)	0.907	megagrams	Mg
TEMPERATURE				
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lanberts	3.426	candela/m2	cd/m2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm2	square millimeters	0.0016	square inches	in2
m2	square meters	10.764	square feet	ft2
m2	square meters	1.195	square yards	yd2
ha	hectares	2.47	acres	ac
km2	square kilometers	0.386	square miles	mi2
VOLUME				
mL	milliliters	0.034	fluid ounces	floz
L	liters	0.264	gallons	gal
m3	cubic meters	35.71	cubic feet	ft3
m3	cubic meters	1.307	cubic yards	yd3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000lb)	T
TEMPERATURE				
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m2	candela/m2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in2

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CHAPTER 1. INTRODUCTION

PURPOSE

Maintaining mobility in freeway corridors is one of the most pressing tasks of State and local transportation departments. As the arteries of a region's transportation system, freeways carry up to 3O-percent of the daily traffic volume in an urban area.   Much of the current Federal funding is geared toward addressing problems in freeway corridors.

With the magnitude of funds being invested in the freeway infrastructure, decisions on when and where to invest those funds must be made wisely. The public expects that funds entrusted to highway agencies will be expended on improvements that do, in fact, benefit the public. More sophisticated analysis techniques, properly used, have the potential for assisting decision-makers in arriving at solutions that will optimize public investment and result in designs that improve the safety and operation of traffic flow. Freeway simulation models are one of the tools available for assisting engineers and planners in developing these more cost-effective solutions.

This report was prepared under a Federal Highway Administration (FHWA) contract entitled "Analysis of Complex Congested Corridor Locations.' The purpose of this project was to apply three freeway simulation models and the procedures in the 1985 *Highway Capacity Manual* (HCM) to real-world situations and to develop guidelines for improving the use of freeway simulation. Each of the models was applied in five case study sites: Seattle; Minneapolis: Milwaukee; Columbus, Ohio; and New York City. The application of the models provided the opportunity to compare their strengths and weaknesses, to suggest possible enhancements to the models, and to develop application guidelines for freeway simulation modeling in general. The three freeway simulation models evaluated included FREFLO, a macroscopic simulation model developed under FHWA contract, FREQ, a macroscopic model developed by the University of California at Berkeley; and FRESIM, a microscopic model developed under FHWA contract. The terms 'macroscopic. and 'microscopic" and the capabilities of the models are described in chapters 2 and 3. This report is directed toward existing and potential users of freeway simulation models, with an emphasis on guidelines for model selection and application.

REPORT ORGANIZATION

This final report covers the subject of freeway simulation modeling from a user's point of view. The following generally describes the theme and content of each chapter:

- Chapter 2 - "Role of Freeway Simulation in Corridor Planning", Design, and Operations: This chapter has been written primarily for those who must determine whether using a simulation model will be a helpful and cost-effective exercise for a particular set of circumstances. it discusses the appropriate role of simulation models in the context of corridor planning, design, and operational analysis overall.

- Chapter 3 - "Description of Freeway Simulation Models": Provides a basic description of the simulation models FREFLO, FREQ and FRESIM, as well as the procedures based on the 1985 HCM.

- Chapter 4 - "Selecting a Simulation Model': Provides information on how to select a particular model or set of models to perform specific tasks. It covers a wide variety of geometric and operational Situations that could occur and indicates how each model (and the HCM procedures) would be employed to address each situation, if it is possible to address that situation it with the model.

- Chapter 5 - "Freeway Corridor improvement Strategies': Examines potential strategies to be considered for the improvement of freeway corridors. information is presented on the characteristics of the strategies and on matching strategies to specific problems.

- Chapter 6 - "Application of Simulation Models in Freeway Design and Operations": This chapter is directed primarily toward those individuals directly involved in the hands-on application of freeway simulation in corridor analysis. It presents a task-by-task process for developing the evaluation framework, identifying measures of effectiveness (MOE's), gathering data, selecting the appropriate analysis tool, calibrating and validating the model, developing alternatives to be evaluated, simulating those alternatives, and presenting results. Selected results from the case study evaluations are used to illustrate various points.

- Chapter 7 - "Case Study Evaluations": Presents a series of five case studies conducted during this project. it summarizes the lessons learned from the process of applying the models in these specific conditions, many of which are reflected in the model application guidelines in Chapter 6. Because the case studies were used during the project as a teaching tool to refine the model application process, the case study applications did not necessarily conform to the process recommended in chapter 6. Each case study incorporated a them8 or emphasis for the analysis, designed to test certain components of the modeling and corridor analysis process. The specific case studies and corresponding analysis themes include:

    - I-5 in Seattle, Washington (evaluation of truck climbing lanes, high occupancy vehicle (HOV) lanes and ramp metering in the context Of a major upgrade).

    - The George Washington Bridge/Cross Bronx Expressway in New York and New Jersey (an incident management analysis).

    - I-94 in Milwaukee, Wisconsin (evaluation of HOV lanes and ramp metering, in the context of potential highway and transit improvements in the corridor).

    - I-70/71 (evaluation of complex weaving sections).

    - I-494 in Minneapolis, Minnesota (evaluation of lane additions with and without HOV lanes, in the context of an existing ramp metering system).

CHAPTER 2. ROLE OF FREEWAY SIMULATION IN CORRIDOR PLANNING, DESIGN AND OPERATIONS

OVERVIEW OF FREEWAY SIMULATION

Freeway simulation is gaining increasing acceptance and popularity as a tool for evaluating freeway improvement alternatives and refining freeway designs. with increasing congestion comes an increasing need for evaluating the interrelationship among freeway sections and among roadway facilities in a given corridor. The evaluation of individual sections one at a time is frequently inadequate to fully consider the implications of traffic flow on freeway design and operations. As the need to evaluate the interaction among sections and facilities increases, so too will the need to employ these more sophisticated analytical techniques. Several freeway simulation models now operate on microcomputers, simplifying the use of the models and opening up opportunities to many engineers previously unable to take advantage of the analysis power these models afford. Yet freeway simulation models hold many potential pitfalls for the unsuspecting. Failure to understand the underlying theory and assumptions, to properly validate the models or to correctly interpret their results may produce erroneous conclusions. The models also have limitations in the situations they are able to evaluate.

Simulation models are simply mathematical methods of approximating what occurs in real life situations. The primary reason for the development of simulation models is to provide an economical way of predicting the outcome of alternative courses of action without actually having to implement the actions. This report provides an extensive treatment of the application of freeway simulation models. a particular class of models designed to assist in freeway corridor planning, design, and operation. Both microscopic and macroscopic freeway simulation models are discussed. These two basic classes of models are distinguished by the following characteristics:

- **Microscopic models** simulate the movement of indiidud vehides, based on theories of car-following and lane-changing. Typically, vehicles enter the section using a statistical distribution of arrivals (a stochastic process) and are tracked through the section in short time steps. A time step of one second is often used, but can be longer. Even with current hardware and software technology, the computer time and storage requirements for microscopic models are large, usually limiting the length of section and amount of time that can be reasonably simulated. However, they are able to evaluate geometric and operational details that macroscopic models are unable to simulate, and time steps longer than one second can be used to reduce computer time. As computer capabilities increase, microscopic models will become more adaptable to the simulation of longer corridors and time periods.

- **Macroscopic models** are generally based on deterministic relationships developed through research on highway capacity and traffic flow through freeway and arterial sections. The simulation for a macroscopic model takes place on a section-by-section basis rather than tracking individual vehicles. Macroscopic models have considerably less demanding computer requirements and are

currently more practical for simulating longer sections. They do not, however, have the ability to analyze improvements and designs in as much detail as the microscopic models described above.

The three simulation models discussed in this report are FREFLO (macroscopic), FREQ (macroscopic), and FRESIM (microscopic). FREFLO and FRESIM have been developed under previous contracts with the FHWA. FRESIM is considered to be the next generation of the microscopic simulation model INTRAS. An evaluation of INTRAS was not included in the scope of this contract. However, INTRAS has been officially released by FHWA and has been applied in a number of settings. Except for a few limitations of INTRAS that are overcome by FRESIM, most of the comments on FRESIM made in this report also apply to INTRAS However, the reader should be aware that there are differences not addressed in this report that could affect decisions regarding the use and application of INTRAS. FREQ has been developed over the last 20 years by the University of California at Berkeley. These models are described in a later section. in addition to the freeway simulation models, the role of the Highway Capacity Software (HCS) analysis program in the corridor evaluation process is discussed. The HCS software is based on the *1985 Highway Capacity Manual (HCM).*

The freeway simulation models discussed in this report are not the only models available for simulating freeway sections. The discussion of the three models is not an endorsement by FHWA or the authors of this report as the only valid method for Simulating a freeway corridor. However, they represent the significant development efforts of FHWA (FREFLO and FRESIM) and extensive development and application of FREQ throughout the U.S. and abroad.

The topics addressed in the remainder of chapter 2 include:

- Overview of the freeway corridor planning, design, and operations process.

- Role of freeway simulation models and other analytical techniques.

- When to consider using a freeway simulation model.

- Overview of the corridor simulation process.

- Major simulation decisions and activities

    - Defining the study area
    - Selecting the simulation time period.
    - Calibrating and validatin the model.
    - Defining and evaluating alternatives.

- Potential benefits, risks, and keys to success.

- Personnel, computer, and time resources required to use freeway simulation models.

DEFINITION OF TERMS

Prior to engaging in a discussion of the details of freeway simulation, a number of terms should be defind to eliminate possible confusion over their use in this report. Some of the key terms are defined below.

- Basic number of lanes - The number of freeway lanes available to traffic flow through an extended length of freeway, excluding auxiliary lanes and merge/diverge lanes.

- Contour diagram - A table showing how a measure of effectiveness (MOE) varies by time period and by section. Time is usually shown on the vertical axis and distance is usually shown on the horizontal axis. Contours are most often shown for speed, density, volume/capacity ratio, and queuing. Contours for level of service, emissions, and noise are aiso possible. Contour diagrams are useful in quickly gaining an overall picture of freeway operation and are particularly useful in validating a simulation model.

- Demand elasticity - The rate at which traffic demand in a corridor or on a facility changes in response to the supply of transportation facilities (e.g., increases in roadway capacity or in the provision of transit service). Demand is inelastic when changes in transportation supply have little or no effect on demand.

- Freeway corridor - A freeway and other major parallel and crossing streets or other freeways that work together to carry urban traffic fro m one geographic area to another. While corridors cannot always be dearly defined, they would often fail within the range of 5 to 30 mi (8.1 to 46 km) long and 1 to 5 mi (1.6 to 8.1 km) wide.

- Incident management - Strategies, procedures and devices for minimizing the impact of traffic accidents and other incidents on the flow of freeway traffic.

- Lane balance - Employing principles of traffic engineering and driver expectancy to serve expected traffic demand and minimize forced lane changes.

- Measure of effectiveness (MOE) - A quantitative measure of traffic performance, used to gauge the degree to which a set of objectives is achieved. They are normally used to quantify how alternatives compare against one another or against a Set of operational standards. Speed, volume, and density are three MOE's often used in freeway analysis.

- Model calibration - The act of refining the model until it produces results that represent, as nearly as possible, the behavior of traffic as measured in the field.

- Model validation - Verification, through comparison of model outputs with field measures, that the model reasonably represents traffic flow.

- Project development - Process used by a transportation agency to define a roadway alignment and cross section and to develop a conceptual design (Or

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preliminary design). This would include mainline lane requirements and interchange layouts. The process also often includes environmental studies.

- Regional - Pertaining to the entire urban area.

- Simulation model - A mathematical formulation used to estimate an actual phenomenon. in the context of this report, a freeway simulation model is used to estimate the flow of actual freeway traffic.

- Speed profile - A plot of speeds (vertical axis) across freeway sections (horizontal axis), used to visualize the locations of congestion for a specific time period. One of the basic outputs of all the simulation models is average speed by section by time period. Profiles can be shown for other MOE's also.

- Subregional - A subarea within a region, normally including a county or large city.

- Time slice - A simulation period in a single simulation run. A simulation run would be composed of a series of time slices over a peak period. Ordinarily, 15-min time slices are used in freeway simulation. However, most models are flexible in defining longer or shorter time slices.

- Travel demand forecasting model - A form of simulation model that predicts traffic demand on the basis of relationships between travel and population/employment or land use data. These models are primarily used to predict future year traffic volume and to provide traffic volume inputs to other simulation models, including freeway simulation models.

OVERVIEW OF THE CORRIDOR PLANNING AND DESIGN PROCESS

There is no single reference that provides a complete overview of the process of planning and designing a freeway or a freeway improvement in the context of total corridor operation. Texts on transportation planning typically address corridor analysis from the perspective of corridor location.   A Policy *on Geometric Design of Urban and Rural Highways* (American Association of State Highway and Transportation Officials (AASHTO), 1994) addresses the more detailed design aspects. Standards for design and operation are established primarily by State departments of transportation. Guidelines for the operation of freeways are established in texts such as FHWA's *Urban Traffic Control Systems Handbook.* Understanding how these processes interrelate provides the framework for determining where and how simulation models can be used.

ROLE OF FREEWAY SIMULATION WITHIN THE REGIONAL CONTEXT

Figure 1 indicates typical transportation planning and engineering processes that take place within a region. Each box in figure 1 represents one broad aspect of the planning, design, and operations process. While the details of the processes and the agencies

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┌─────────────────────────────────┐
│ REGIONAL AND SUBREGIONAL        │
│ POLICIES AND OBJECTIVES         │
└─────────────────────────────────┘
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┌──────────────────┐   ┌─────────────────────────────────────┐   ┌──────────────────┐
│ REGIONAL         │   │ REGIONAL TRANSPORTATION             │   │ INTERFACE WITH   │
│ ENVIRONMENTAL    │   │ PLAN AND IMPROVEMENT                │   │ OTHER PLANS      │
│ ANALYSES         │   │ PROGRAM                             │   │                  │
│  ● Emissions     │   │  ● Regional travel demand forecasting│   │                  │
│    Inventory     │   │    Models                           │   │                  │
│    Models        │   │  ● Interface with land use allocation│   │                  │
│                  │   │    models                           │   │                  │
└──────────────────┘   └─────────────────────────────────────┘   └──────────────────┘
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┌─────────────────────────────────────┐
│ SUBREGIONAL TRANSPORATION           │
│ PLANS                               │
│  ● Focused versions of regional travel│
│    demand models                    │
│  ● Application of generalized highway│
│    capacity criteria                │
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┃ PROJECT DEVELOPMENT                  ┃
┃ (FREEWAY CORRIDORS-                  ┃
┃ GEOMETRIC & OPERATIONAL)             ┃
┃  ● Focused corridor versions of regional┃
┃    travel demand model (if necessary)┃
┃  ● Traffic refinement procedures     ┃
┃  ● 1985 HCM chapters 3-6             ┃
┃  ● Freeway simulation models         ┃
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┌─────────────────────────────────────┐
│ ENVIRONMENTAL ASSESSMENT/           │
│ EMPACT STATEMENT                    │
│  ● Emission concentration models     │
│  ● Emission inventory models         │
└─────────────────────────────────────┘
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Boxes outlined by a bold line represent primary realm of application of freeway simulation models.

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┌─────────────────────────────────────┐
│ DESIGN AND IMPLEMENTATION           │
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┏━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━┓
┃ ONGOING OPERATIONAL                  ┃
┃ ASSESSMENT & MODIFICATION            ┃
┃  ● 1985 HCM chapters 3-6             ┃
┃  ● Freeway simulation models         ┃
┗━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━┛
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Figure 1. Summary of analysis techniques and models appropriate for
transportation planning and operations activities within a region.

responsible for them may vary from region to region, virtually every major urban area addresses these components.

Within these processes, there are a variety of models and analytical techniques commonly used. The role of freeway simulation models becomes clearer when one also understands the primary roles of the other analysis tools. The following generally discusses each of the processes and where some of the more significant models and analysis tools, including freeway simulation, fit into the various steps. The same model class may play different roles at various stages.

- **Regional and subregional policies and objectives:** These provide guidance and direction for the remainder of the planning, design, and operations process. There are normally no analytical models associated with the development of policies and objectives.

- **Regional transportation plan and Improvement program:** This is a legally mandated process for identifying and programming transportation improvements, with emphasis on the long range. It is developed in parallel with other regional plan components, such as housing and air quality. Models applied in this stage, and their typical functions, include:

  Regional travel demand forecasting models:

  - Development of long-range travel forecasts for major regional transportation facilities. The forecast would normally emphasize the facilities in the regional transportation improvement program, but may not include sufficient detail to adequately forecast peak hour traffic for an individual facility.

  - Serve as the basis for numerous derivative models, used for analyzing highway and transit alternatives within specific corridors or subareas.

  - Analysis of the transportation impact of alternative regional land use scenarios, in association with studies of regional growth or for potential growth within specific subareas.

    Provide data on travel demand and speed that could be used for analysis by an air quality model.

  - For a freeway, a primary result of an analysis with a regional travel demand forecasting model or its derivative corridor and subarea models is the establishment of basic lane requirements to meet future demand (i.e., to achieve corridor objectives). Some of the strengths of regional travel demand models are the ability to forecast modal shifts, the ability to predict spatial shifts in demand brought about by changes in the transportation system, and the ability to forecast future changes in demand. This demand analysis orientation is not present in the freeway simulation models.

Land use allocation models:

- Assist in the development of regional forecasts of land use which, in turn, serve as input to the regional travel demand forecasting models. Not every urban area uses land use allocation models, but they are being increasingly interfaced with transportation models.

- **Regional environmental analyses:** Each region is obligated to evaluate the environmental impact of the implementation of transportation plans and programs. A major part of this evaluation centers around air quality analysis, the need for which has been reinforced by the 1999 Clean Air Act Amendments. At this level in the regional process, inventory-type emissions analysis models are normally used to predict the estimated quantities of pollutants emitted for the area forecast. Typically, they use the number of trips by zone, link volumes, and link speeds as the primary input, taken from runs of the regional travel demand forecasting model. Output includes tons of emissions per day [e.g., carbon monoxide (CO), nitrous oxides (NO_x), and reactive organic gases such as hydrocarbons (HC)]. It is important to have peak period (as opposed to daily) volumes and speeds from the regional transportation model (or to develop peak period factors) to properly estimate emissions.

- **Subregional transportation plans:** These can range from a countywide plan to a plan for a large city or major subarea that has characteristics indicating that it should be addressed as a unit. A citywide general plan or comprehensive plan may be a form of subregional plan. In the transportation component, the issues dealt with normally include corridor location and overall lane requirements to accommodate future needs. Like regional plans, subregional transportation plans are often developed in conjunction with land use and air quality plans. Analysis techniques employed at this level typically include:

  - **Focused (or windowed)** versions of the regional travel demand forecasting model. A focused model adds additional network and zone detail in the area being analyzed while aggregating network and zone information in areas removed from the study area. A windowed model extracts a subset of network and zones representing the study area, interacting at the regional level with volumes at the cordon points of the window. Depending on the nature of the study and the geographic coverage of the model, a focused or windowed model may be adequate to provide forecasts for a specific corridor study.

  - Generalized capacity analysis techniques. For freeways, chapter 4 ("Basic Freeway Segments") would be the greatest level of detail used, with emphasis on overall lane requirements to meet future needs. The more detailed procedures would follow in a later stage (primarily in the project development stage).

- **Project development** (for both freeway corridor design and operations): Most State and local departments of transportation have processes for 'project development' the term commonly used to describe the process of defining lane

requirements and operational techniques to improve freeway corridor traffic flow. It could also be applied to transit corridor development, but the context of this report is freeway corridors (including HOV facilities). Project development often includes preliminary (conceptual) design, environmental evaluation, and cost-effectiveness evaluation. It could include consideration of both short-term and long-term improvements. Project development activities normally begin with the definition of alternative concepts or designs, and the development of a recommended concept that can then be taken into the design stage, given that it has been accepted by the community and approved through appropriate legal channels. Environmental evaluation would be included as a significant component of project development, but is shown as a separate box in figure 1. Several department of transportation (DOT's) provide manuals or handbooks on project development. Models employed at this stage may include:

- Focused (or windowed) versions of regional travel demand forecasting models. This could include further refinements of subregional models, or the subregional model may already be appropriate for this analysis. In either case, the model needs to provide the basis for making interchange-level forecasts for peak periods. The requirements for doing this are too significant to be included in a discussion in this report. If freeway alternatives include major changes in capacity, travel demand forecasting models may be needed to provide different forecasts for each alternative.

    Refinement of forecasts from travel demand models. The output from travel demand models (even focused models) are seldom sufficient to provide traffic forecasts for freeway corridor project development. Traffic refinement procedures such as those in National Cooperative Highway Research Program (NCHRP) Report 255, *Traffic Data for Urban Area Project Development and Design,* are needed to improve the estimation of travel forecasts. These refined volumes serve as the inputs to future year runs of the freeway simulation models. Failure to conduct thii step could result in dramatic inaccuracies in later steps.

- Freeway simulation models. These could serve the following functions in the project development process:

    - Refinement in the basic number of lanes to achieve corridor objectives. This primarily includes eliminating or reducing the impact of bottleneck sections that would not have been apparent from the more generalized determination from the results of the travel demand modeling.

    - Determination of the need for auxiliary lanes, reconfiguration of ramp merges and diverges, and other microdesign issues.

    - Alternatives analysis. Estimation of changes in MOE's for alternative designs, assuming demand remains constant. Comparisons could be made in vehicle miles of travel (VMT), vehide hours of travel (VHT), person hours of travel (PHT), etc. These could be used to develop cost-effectiveness measures (or benefit/cost ratios) to assist in the selection of alternatives. The freeway simulation models currently

have no ability to simulate the areawide impact on traffic demand of a geometric improvement. FREQ has a limited ability to simulate demand shifts between the freeway and an arterial.

- Simulation of special traffic operations measures that cannot be simulated using other techniques (e.g., incident management strategies and ramp metering).

Capacity analysis software. These procedures would be used either as a secondary procedure to provide capacity input to freeway simulation models (assuming simulation models were used), or as the primary procedure for the evaluation of freeway designs.

- As primary procedure: The full range of procedures in chapters 3,4 and 5 of the 1985 HCM would be used. The freeway capacity analysis procedures are primarily oriented toward freeway design (determination of lane requirements on a section-by-section basis). They would not be used to generate comparative estimates of VMT, VHT, etc. The procedures would use volumes from a travel demand forecasting model as an input and would refine any lane determination derived from the forecasting model: While there are weaknesses in the HCM procedures, they represent the only accepted method of section-by section capacity evaluation. Weaknesses and precautions in using the HCM procedures for either input to the simulation models or as the primary analytical tool will be discussed later in this report.

- As secondary procedures: The HCM provides section-by-section capacity input into macroscopic freeway simulation models. Chapters 3,4 and 5 of the HCM would again be used.

- **Environmental assessments (EA) and environmental Impact statements (EIS):** The primary traffic-related impact considered are that of air quality and noise. Air quality has become a particularly important concern, and is addressed by several models:

  - Concentration models (such as CAL3QHC and CALINE4) predict concentrations of pollutants in parts per million, based on traffic volumes, speeds, and stops from nearby roadways, in the context of background pollutants and meteorological conditions.

  - Emissions inventory models. These are the same as those models referenced earlier In component 2, but are applied at a corridor level. Several of the freeway simulation models include algorithms to estimate emissions. The determination of whether to use the simulation model or a separate emissions inventory model to interface with the focused travel demand forecasting model is an important decision. The following general guidelines apply:

- Use an emissions inventory model linked to the focused travel demand model if traffic demand changes significantly among the freeway alternatives being analyzed. A major capacity increase, for example, will normally draw more traffic into the corridor, reducing demand on other facilities. If the focused travel demand model is a daily model only (and does not have a peak period assignment capability), it may not be capable of reasonably accounting for peak period capacity changes. The metropolitan planning organization in the region should be consulted to determine the most appropriate approach.

- Use the emissions estimation capability of the freeway simulation model if traffic demand does not change significantly with the alternative. If demand is held constant when, in fact, it is likely to change (as with a major capacity increase), the emissions on the freeway itself will be underestimated. If the new demand numbers for each alternative are used in the freeway simulation model, the *total* emissions will probably be overestimated, because it will not account for emissions reductions that occurred on parallel facilities (from which traffic volume may have been diverted with the improved facility). Failure to account for these effects may result in an EA or EIS being open to challenge.

- **Design and Implementation:** The major analysis activities should have been completed by the time construction design plans are ready to be prepared. It is possible that alterations in the conceptual design will need to be considered within the process of preparing plans, specifications, and estimates, but it is unusual to require further analysis at a level that would require freeway simulation. Therefore, it is assumed that simulation models would not play a role in this component of the process.

- **Ongoing operational assessment and modification:** Examples of activities in this component could include minor geometric modifications, changes in a ramp metering strategy, or the fine-tuning of other operational procedures. Freeway simulation models have a potential role at this stage, particularly if they are already validated and available for use with current data

WHEN TO USE A SIMULATION MODEL

As Indicated above, freeway simulation has its primary application in the project development stage and in the refinement of ongoing traffic operational strategies. But within these areas, a major issue is whether the advantages of freeway simulation are sufficient to warrant the investment in its application. There is a perception that simulation will be substantially more diicult, risky, and costly than the charted waters of the HCM. The decision to use simulation often is weighed as a direct comparison with the availability of the HCM procedures and engineers' general understanding of its capabilities. Therefore, a contrast between approaches afforded by freeway simulation and by the HCM is appropriate to put both procedures in better perspective.

Contrast Between the HCM Procedures and Freeway Simulation

- The HCM procedures are widely recognized and their application reasonably well understood by the engineering community and many representatives of local government. Simulation still retains a degree of mystery and uncertainty in many agencies, because it has been used much less often.

- Freeway simulation is perceived to be a much more expensive and time-consuming method of analysis than the HCM. The extent to which this is the case depends on the length of the corridor and the number of alternatives. The longer the corridor and the greater the number of alternatives, the more competitive simulation models become in terms of analysis time. In fact, simulation models may actually save time if multiple alternatives must be evaluated.

- The HCM procedures examine one section at a time and are unable to evaluate interactions between sections (e.g., queue spillover). One of the most powerful aspects of freeway simuiation is the ability to determine the effect of geometric and traffic operational strategies upstream and downstream of the section or sections to which the strategies are applied.

- The HCM cannot evaluate congested conditions. Freeway simulation models are designed to evaluate congested conditions and the change in level of congestion brought about by various strategies.

- The principal use for the HCM procedures is in designing a freeway to operate at a desired level of service. As long as upstream/downstream interactions are not significant, the procedures can be used for that purpose.

- The HCM procedures cannot be readily validated for a given site, particularly in a congested freeway section. Freeway simulation models are more readily validated, as they provide addiional information against which validation can occur (e.g., congestion patterns). The ability to validate the models gives additional confidence that the procedures do, in fact, provide a reasonable representation of reality. With the HCM procedures it is normally assumed that this is the case, when in fact more fine-tuning is needed than is normally thought to be necessary. The general acceptability of the HCM procedures can create a false sense of security if they are not adequately fine-tuned to the situation.

- The Highway Capacity Software (HCS) contains limitations that inhibit the user from being able to evaluate a full range of conditions. For example, freeway capacity under ideal conditions is limited in the HCS to 2,000 passenger cars per hour per lane (pcphpl). Research has indicated (and experience on this project has verified) that this value can be 2,200 to 2.300 pcphpl. Several of the case study models could not be validated unless these values were used. The HCS could not accurately reflect actual conditions with the 2,000 pcphpl limitation. Manual adjustments were possible, however. There are also significant weaknesses in the HCM weaving and ramp merge/diverge procedures.

- Freeway simulation models are designed to produce system-related output, some of which can be used directly in tables and reports or can be readily reformatted to serve that purpose. The results of HCM runs must be assembled and put into tabular or graphic form independently.

- There are situations and strategies that the HCM is unable to evaiuate. For example, the procedures are not designed to evaluate incident management strategies or ramp metering.

- The HCM procedures are easy to learn and to use. The application of freeway simulation models normally requires additional training.

- Freeway simulation models could be considered overkill for certain situations. Discernment is needed for deciding when to apply a model and which model to apply.

SItuatlons for Which a Freeway SImulatlon Model Is Approprlate

Use of a freeway simulation model should be considered (in lieu of or in conjunction with the HCM) under the following conditions:

- If locating the optimum point for transition in the number of basic lanes on a freeway is a particularly important issue (i.e., if being off in the transition point is likely to result in substantial additional congestion or in substantial unnecessary expenditure).

- If the freeway is congested or could potentially be congested in the horizon year. A simulation model would be needed to estimate the extent of congestion remaining (i.e., this could not be done using only the HCM procedures).

- If the operation of a section of freeway is significantly dependent on the adequacy of flow through weaving sections, multiple ramp merge/diverge areas, or other complex bottlenecks. The more complex the section of freeway, the more beneficial a model will be, because it is able to consider interactions between sections.

- If several alternative design configurations are to be tested and evaluated. The more alternatives there are to be tested, the more a simulation model will be of benefit.

- If a cost-effectiveness or benefit/cost comparison is to be conducted. This would require estimating changes in VHT, PHT, fuel consumption, or emissions with and without the proposed improvement (this cannot be done with the HCM procedures).

- If it is desired to evaluate preferential strategies for high occupancy vehicles (HOV's) or traffic operational measures such as ramp metering, incident management strategies, or the effect of construction/maintenance operations. These cannot be easily evaluated with the HCM procedures.

Within the two classes of freeway simulation models (macroscopic and microscopic), the microscopic models are conceptually more appealing, but are computationally intensive. They accommodate more of the variables accounting for vehicle/driver/highway interaction and are not limited to dealing with the "chunks" of time in which the macroscopic models operate. The macroscopic models work in terms of aggregated time intervals, which sacrifices the ability to more realistically simulate traffic flow. Yet both types of models currently have their appropriate role in freeway corridor analysis. As computer power increases and software becomes more efficient, the faster but more aggregate macroscopic models can be expected to give way to the more detailed simulation capability of the microscopic models. Chapter 4 discusses the strengths and weaknesses of the two model classes in more detail and provides guidance for selecting the appropriate model based on the strategies and situations being evaluated.

Conditions for Which Freeway Simulation May Not be Appropriate

Some situations may advise against freeway simulation. The use of a model may be overkill in certain conditions, or scheduling or resource problems may make use of simulation impractical or risky. The following represent some basic guidelines on circumstances that suggest a model not be used:

- Basic planning-level evaluation - If only the basic number of lanes on a freeway is the issue (a long-range planning-level evaluation prior to project development), simufation is usually not appropriate. Basic per-lane capacity values based on the HCM are probably adequate.

- Interchange configurations - A freeway simulation model will not assist in the development of interchange configurations. Its focus is on mainline flow. Eventually, microscopic models may be able to assist In interchange design by providing improved ramp capacity values.

- Predicting changes in traffic demand - Simulation models cannot predict changes in demand in response to a geometric or operational improvement. This would need to be done by another analytical tool and the results of that analysis would be provided to the simulation model.

- Time available - While a model can very quickly evaluate geometric and operational alternatives once it is calibrated and validated, there is a significant lead time to making the model operational. The amount of time available for conducting a project may not allow ample time for the development of the model. Chapter 6 presents a typical schedule for the tasks associated with simulation modeling.   If data are available, the development of a validated freeway simulation model could conceivably be accomplished in as little as two person-months. The

simulation of alternatives could be accomplished in one additional person-month, assuming that forecasts are available and alternatives have been defined. If the staff is not already familiar with the models, these time estimates will be too short. But the initial investment in staff time will pay off in the long run with greater efficiency and proficiency and proficiency with the application of models for additional applications.

THE SIMULATION PROCESS

As indicated previously, project development is the stage in which freeway simulation models find their most appropriate application. Figure 2 illustrates a generic project development process, with emphasis on the traffic engineering and conceptual design activities (leading up to the environmental process). It specifically indicates how freeway simulation models can be employed within the context of that process. The figure does not include steps in the environmental evaluation of a project, although simulation models may provide input to that evaluation.

A specific corridor may require examining short-term solutions, long term solutions or both. Figure 2 indicates three basic phases: Phase One - Model Selection and Calibration; Phase Two - Short-Term Analysis; and Phase Three - Long-Term Analysis. Phase One is required to develop the data and analysis tools to the point where alternatives can be evaluated. It also establishes the decision-making framework (e.g., defining corridor objectives, operational standards, etc.). It can comprise over half of the analytical effort, particularly if substantial data collection is required.

The project development activity could indude only short-term evaluation, only long-term evaluation, or both, depending on how the project scope is defined. These are distinguished primarily by how long it would take to implement the recommended solutions. Short-term would be viewed as projects implementable within a 1-to 5-yr timeframe and would ordinarily not involve major lane reconstruction (although adding a lane through restriping could be considered in the short term category). Short-term strategies primarily include minor lane additions or extensions, corrections to ramp merging/diverging problems, and operational strategies such as ramp metering and incident management Although the models may be used for new freeway facilities as well as reconstruction and operations projects, the emphasis of most applications will be reconstruction and operations.

The short-term and long-term paths have many of the same steps. One of the key features distinguishing short-term from long-term is how the traffic forecasts are treated. A long-term evaluation often requires additional effort in forecasting, as it becomes more difficult to predict volumes through trend line analysis.   Large-scale projects are also more likely to have regional effects, and traffic demand tends to be influenced by the alternatives themselves (e.g., a major capacity increase draws additional traffic into the corridor). The question must be asked, "Will demand change significantly with the implementation of the improvements?" If so, additional traffic forecasts will normally be required, not only to more accurately reflect what demand will be with the improvements, but to properly address emissions analysis requirements, which have become more rigorous with the enactment of the 1990 Clean Air Act. Chapter 6 describes the project development process for each task shown in figure 2.

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PHASE ONE:
STUDY PREPARATION
AND MODEL
CALIBRATION

Task 1
IDENTIFY NEED
FOR STUDY

Task 2
DEFINE CORRIDOR
OBJECTIVES

Task 3
DEFINE MEASURES
OF EFFECTIVENESS

Task 4
DEFINE HORIZON YEAR,
STUDY AREA, AND
TIME PERIODS

Task 5
SELECT ANALYSIS
TOOLS

Task 7
IDENTIFY OR
ESTABLISH
GEOMETRIC
STANDARDS

Task 6
ESTABLISH
OPERATIONAL
STANDARDS

Task 9
DOCUMENT EXISTING
GEOMETRICS AND
OPERATIONS

Task 8
COLLECT TRAFFIC
DATA

Task 10
SET UP
MODELS

Task 12
IDENTIFY PROBLEMS
& POSSIBLE CAUSES

Task 11
CALIBRATE AND
VALIDATE MODELS

Short-Term Analysis   Long-Term Analysis

Task 13
IDENTIFY
CANDIDATE
SHORT-TERM
STRATEGIES

Task 19
DEFINE FUTURE
REGIONAL CONDITION

Task 20
OBTAIN
TRAFFIC
FORECASTS

Task 14
SIMULATE
SHORT-TERM
STRATEGIES

Task 21
SIMULATE FUTURE
NO-BUILD CONDITION

Task 15
EVALUATE
RESULTS

Task 22
IDENTIFY FUTURE
PROBLEMS AND
PROBABLE CAUSES

Task 16
REFINE
STRATEGIES
(IF NEEDED)

Task 23
IDENTIFY CANDIDATE
LONG-TERM
STRATEGIES

Task 17
MAKE
SHORT-TERM
RECOMMENDATIONS

WILL
DEMAND CHANGE
SIGNIFICANTLY WITH
IMPROVEMENTS?

YES

Task 24
OBTAIN
MODIFIED
FORECASTS

PHASE TWO:
SHORT-TERM
ANALYSIS

Task 18
DOCUMENT
RESULTS

NO

Task 25
SIMULATE LONG-
TERM STRATEGIES

Task 26
EVALUATE RESULTS

Task 27
REFINE STRATEGIES
(IF NEEDED)

PHASE THREE:
LONG-TERM
ANALYSIS

Task 28
MAKE LONG-TERM
RECOMMENDATIONS

Task 29
DOCUMENT RESULTS

Figure 2. Generic project development process,
with emphasis on traffic engineering perspective.

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BASIC SIMULATION DECISIONS

Several decisions must be made early in the simulation process that will define the course of the evaluation. Task 4 in figure 2 indicates the need to define the horizon year, the study area, and the time periods to be simulated. While this activity takes relatively little calendar time, the decisions must be made carefully to avoid problems later in the project Considerations for each decision are discussed below.

Horizon Year

- A basic question for the study is whether it should examine short-term improvements, long-term improvements, or both. If design for long-term improvements is the emphasis of the study, the horizon year would normally coincide with the year currently used in the region for long-term planning. Using the same year or set of years is important, as the study will need to draw from either existing forecasts or forecasts modified from the regional planning model.

- If only short-term improvements are to be analyzed, the horizon year could be established as 1- to 5-yr from the existing condition, anticipating reliance on growth factors for any short-term traffic forecast.

Study Area

- The study area is also defined on the basis of the types of improvements to be evaluated. Long-term improvements, which tend to affect a larger geographic area, usually require a larger study area than short-term improvements, depending on the exact nature of those improvements.

- Typical corridor lengths - For a major corridor study, it is not unusual to have a corridor of 15 mi (24 km) or longer. There are interactions among corridor subsections that can easily extend this length. In some cases, however, the evaluation may focus on a specific trouble spot, such as a weaving section. This could result in a section length of as little as one-half mi (0.8 km). However, if queues extend upstream from the weaving section, or if they may form downstream from the weaving section once the problem is solved, a much longer section could be needed to fully evaluate implications of the solution. The length should extend upstream of a bottleneck to include all congestion caused by that bottteneck This ability to evaluate the upstream/downstream interactions is one of the primary reasons for the existence of freeway simulation models.

- Minimum study area length - A key criterion to defining the study area is the interrelationship among congestion problems within a corridor. If, in the no-build condition for the horizon year, traffic queues are expected to extend continuously for a certain length, that will define the minimum study section. The study area should extend at least one-half mi (0.8 km) downstream from existing bottlenecks or anticipated future bottlenecks. It is also important not to just terminate the

study area at a jurisdiction's border, but to rely on the traffic interrelationships as a primary criterion. Political boundaries may also have some influence from the point of view of responsibility for future design contracts, but it is still important to apply the minimum corridor criteria and not arbitrarily end at a jurisdictional boundary.

- Maximum study area length - The maximum length of the study corridor has two potential limitations: the capabilities of the models and the traffic interrelationships in the corridor. Often, the corridor will have natural boundaries on which its definition can be based. For example, a natural corridor would be a freeway with one end in the suburbs and the other terminating downtown. Such a corridor may also have natural intermediate breaks, such as a major circumferential roadway, river, or mountain range.

- Corridor width - Depending on the physical layout of the corridor, the corridor width can include only the freeway or the freeway plus several parallel arterials or other freeways. If parallel arterials are nearby or can be expected to be built nearby, the arterial should at least be thought of as a component of the project development or operational analysis process. One of the solutions to the freeway could, in fact, be improving flow on the arterials or constructing new parallel roadways. In many cases though, the freeway alone would be sufficient.

Analysis Time Periods

- Selection of peak periods to study - Corridor studies for analysis of design and operations will almost always be directed toward the peak weekday periods. The peak period should be selected to include not only all hours during which congestion currently exists, but hours during which congestion could occur in the horizon year. This implies a considerably longer simulation period than might otherwise be required. Simulation must begin well before the beginning of the congested period; It should never begin in the middle of a congested period. Therefore, the simulation time should be initiated at least 30-min prior to the expected onset of congestion, to ensure that this transition period between no congestion is properly simulated. Beginning the simulation after the onset of congestion will produce serious errors in the results. The necessary time for beginning the simulation can be determined from examination of the volume data for the horizon year, determining how close the volume per lane is to capacity. If the simulation is being used for highway design, it should extend at least 10- past the peak 15-min period. Normally, the simulation should not end until the simulated congestion dissipates in the horizon year for the no-build condition. This is particularly important if the purpose is to compare vehide miles, vehicle hours, emissions, and other aggregate peak period statistics (i.e., a cost effectiveness-type evaluation). This could, in many cases, be 10- or more beyond the current end of the peak period.

- Combination of time periods and directions to be simulated - If the primary problem being addressed is freeway design, one peak period per direction is often sufficient to establish the design requirements. While the basic number of lanes is

normally the same for both directions, ramp configurations may be such that the design in one direction will not mirror the design for the other. Therefore, the simulation of both directions is normally required. Unusual traffic patterns or similar levels of traffic volume may require a second peak period to be analyzed, but this is not usually the case. Some incident management and construction traffic management analyses may require evaluation of off peak period flow.

MODEL CALIBRATION AND VALIDATION

Model validation is the confirmation by the analyst that the model does, in fact, provide a reasonable approximation of reality. Model calibration is the process one follows to achieve validation, If simulation models were nearly perfect tools and if the underlying theory was always accurate, one could argue that model calibration and validation would not be necessary. However, freeway Simulation models are still relatively young, and the theory represents significant simplifications from the many complex variables affecting traffic flow. While some agencies have made a practice of not going through the calibration and validation stage, taking this step is highly encouraged for the following reasons:

- It provides another possible check on glaring errors that may have been introduced in the model coding stage (even errors in the coding of existing geometrics).

- Once complete, the validation provides an assurance to the analyst and to those making decisions based on the model that the model can be relied upon to produce reasonable answers.

- It provides a way of checking the adequacy of the theoretical basis for the models. While this Is more of a model development concern, it is an issue of which the model user should be aware and which may need to be brought to the attention of the model developer.

Specific steps and criteria in model calibration and validation are addressed in chapter 6. However, the reader should at least understand some of the basic criteria for determining whether a model has been adequately validated:

- Traffic volume at Intermediate points on the mainline - If traffic volumes at on-ramps and off-ramps have been consistently measured on days that are similar in' traffic volume characteristics (and during which no incidents have occurred), the volumes computed on the mainline at intermediate points in the freeway section should match reasonably well with the actual measured volumes. This comparison Is particularly important at bottleneck locations. Discrepancies can indicate that either the ramp volumes or mainline volumes contained an error. It is important to remember that traffic will be accumulating within the freeway section as the congested period is entered into (i.e., input will be greater than output). When moving out of a congested period, output will be greater than input Mainline Simulated volumes should be within at least lo-percent of actual volumes. Freeway simulation models are highly sensitive to changes in volume, and a greater degree of accuracy in volume must be expected of a freeway simulation

model as opposed to a regional travel demand forecasting model (for which validated peak hour volumes could easily be greater than lo-percent higher or lower than actual volumes).

- Queue contours - Do congestion patterns indicated in the model-generated queue contour match what is observed to occur in the field, both by time within the peak period and within appropriate sections of the freeway? Figure 3 shows a comparison of queue contours, one derived from a model, the other from field observations. It is difficult to develop a quantitative measure for comparing queue contours, but the simulated bottlenecks indicated by the characteristic upstream queue shouid be in the same area as the actual bottlenecks, and the duration of congestion and length of the queue should be similar.

- Speed profiles and contours - Do the profiles and contours reasonably match what occurs in the field? Figure 4 shows a speed profile, comparing the results of the modeling run with field travel time data for the Same freeway and time period. Dips in the speed profile should occur in the same vicinity, and simulated speeds should typically be within 5 to 10 mi/h (8 to 16 km/h) of the actual speeds for most sections.

- Trip time by time slices - A comparison of model trip time through the corridor (or through subsections) with measured trip time (from travel time runs) should produce similar results. Typically the plot of predicted trip times should be within ±10-percent of measured.

Significant precautions should be understood in comparing model results with travel time data. Errors can occur in data wllected in the field as easily as they can creep into the modeling process. Unless the travel time data is property wllected, it may not represent an adequate basis upon which to judge the validity of a simulation. Several items of which the analyst should be particularly cognizant are listed below:

- The travel time runs and volumes must both represent the conditions (day of week, season of year, etc.) that one hopes to replicate in the model. For example, to expect a good validation for a simulation model that uses volumes collected in the spring by comparing the results with travel time runs conducted in the summer would be futile. Ideally, the volumes and travel time data should be collected on the same days.

- Be cognizant of the potential effect of traffic incidents and other unusual conditions on both volumes and travel time runs. Even incidents that Occur well upstream of the simulated section can significantly affect traffic Operations in the section being simulated. Major downstream incidents can also have an effect, even if queues do not back into the simulated section, by influencing drivers to divert from the freeway. The best insurance against having data sets (volume or travel time) tainted with these effects is to have a data collection team that knows the normal congestion patterns in the collection team that knows the normal congestion patterns in the corridor and understands the importance of having a dean set of data from which to construct the simulation model.

TIME
SLICE .... DIRECTION OF TRAVEL ----> .... BEGIN
TIME
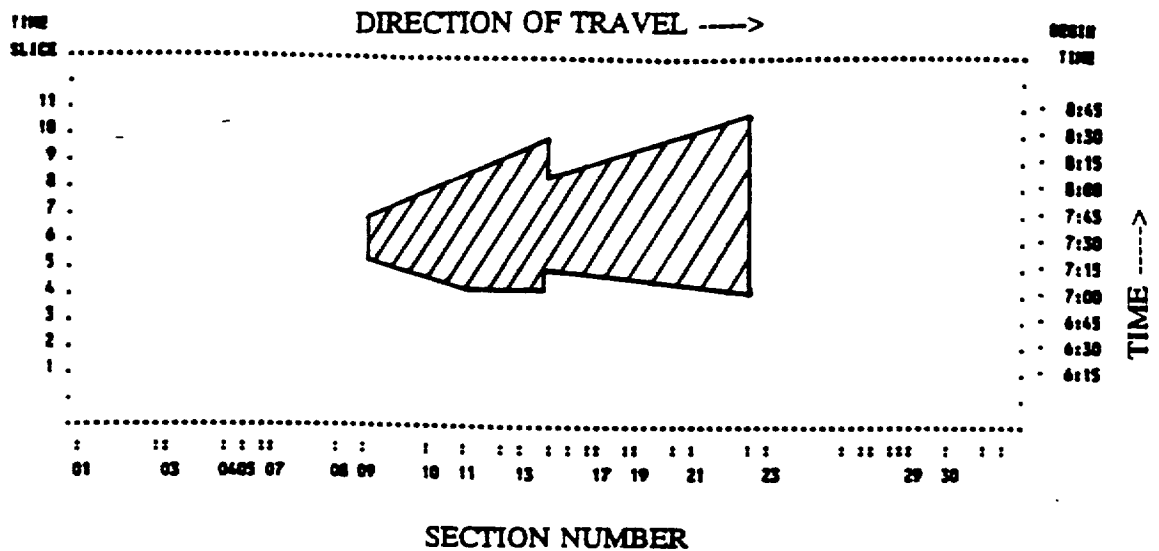
A. Observed Queuing Pattern

(Estimated by individuals knowledgeable of the corridor)

TIME
SLICE .... DIRECTION OF TRAVEL ----> .... BEGIN
TIME

* Indicates area of queuing

SECTION NUMBER
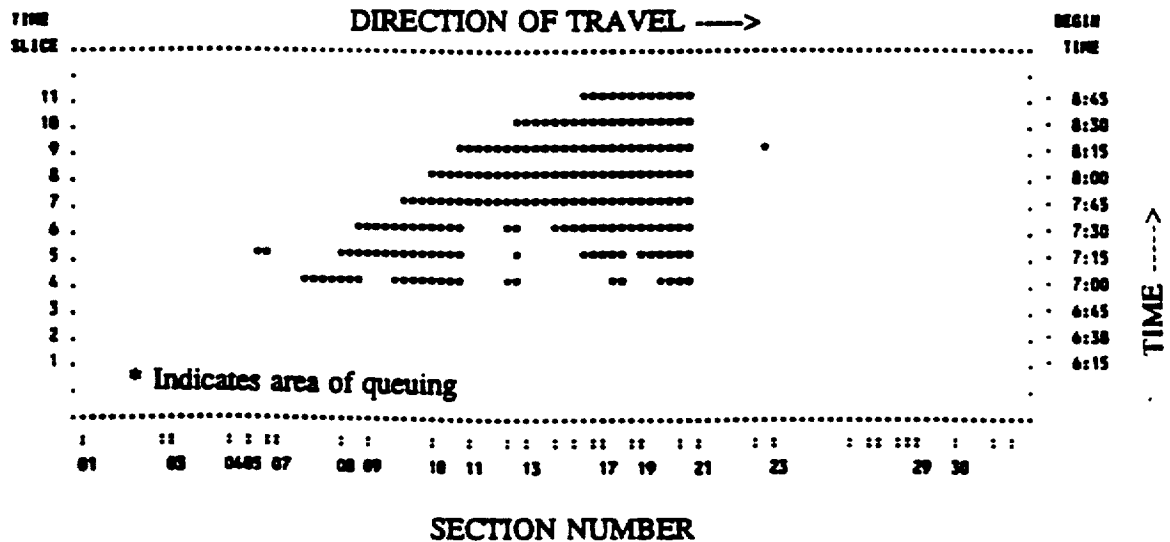
B. Simulated Existing Queuing Pattern

Source: Milwaukee I-94 case study

Figure 3. Sample comparison of observed and simulated
queue contours for the existing condition.

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MILWAUKEE I-94

YEAR 1989 EXISTING CONDITIONS

7:15 - 7:30 A.M. Speed Profiles

1 mi/h = 1.61 km/h

-□- SIMULATION ┼ ACTUAL

Source: Milwaukee I 94 Case Study
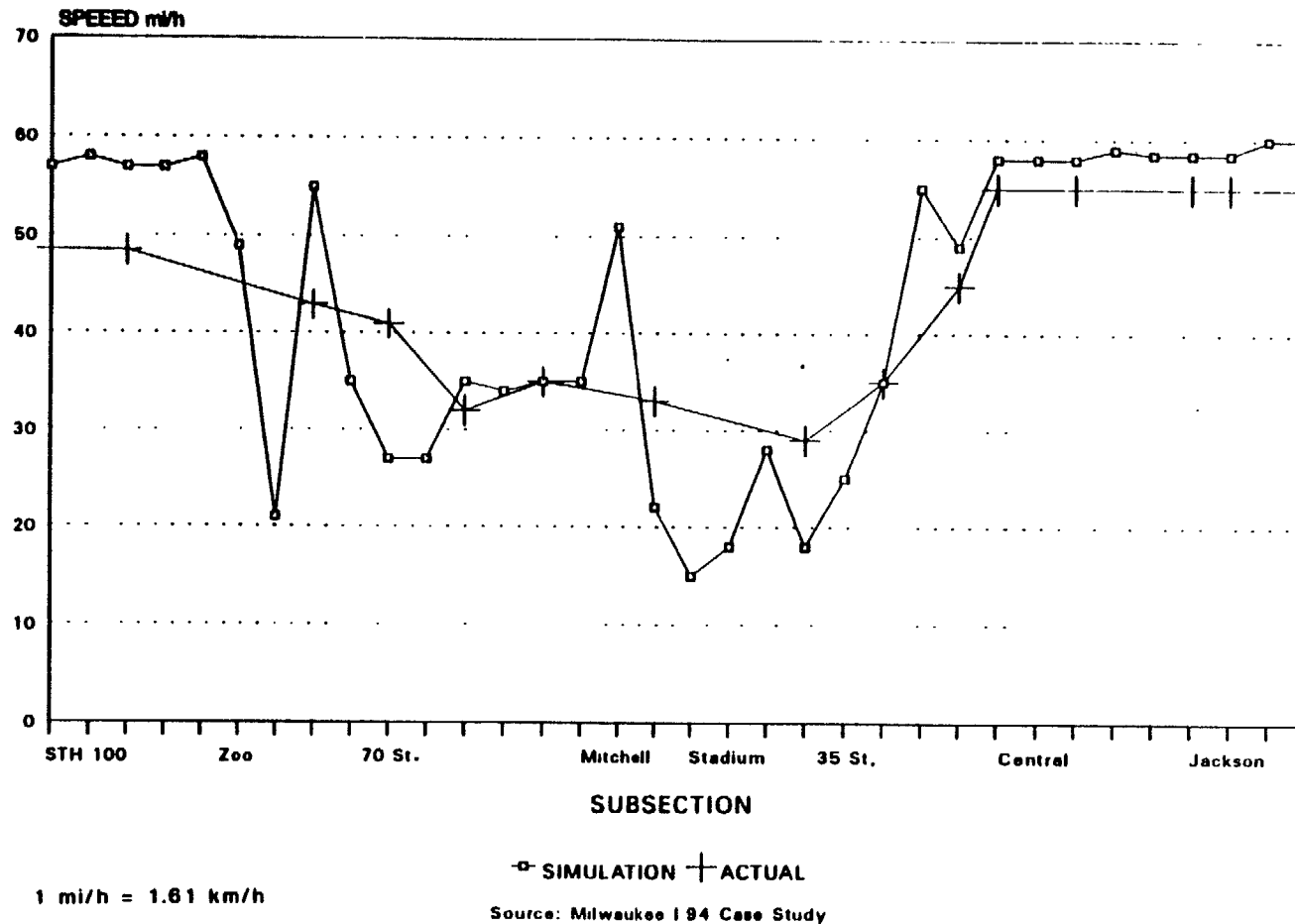
Figure 4. Sample speed profile: comparison of simulation with actual measurements.

- Ideally, each simulated time slice should be represented by travel time data. However, time slices that are currently not congested (i.e. speeds are near the speed limit) should not require travel time data, as long as the uncongested condition can be confirmed from other observations or data. The travel time results should be checked for reasonableness against known congestion patterns.

- Differential travel times may exist among the mainline lanes. A standard model output is average mainline speed across all lanes. If travel time runs were conducted in a lane that had a substantially different Speed profile (e.g. where a queue was caused in the right mainline lane by traffic backing up an off-ramp), a false indication of existing operation would be created. Those conducting the runs must recognize that an average condition is to be replicated and should exclude the runs that do not represent this condition.

It is unusual to have a perfectly matching set of simulated and actual conditions the first time through a modeling run. Typically, between 5 and 20 computer runs may be required before an acceptable validation level is achieved. The information a modeler examines to confirm whether or not a model is validated is a distinctly different issue from what must be adjusted to achieve validation. The nature of possible adjustments, including capacity and design speed or free flow speed, is a more complex subject, and is treated in chapter 6.

KEYS TO SUCCESS IN USING FREEWAY SIMULATION

A positive, useful experience in the application of freeway simulation models is dependent on a number of factors. Freeway simulation should not be expected to answer all the questions, nor should it be totally neglected as an option. The following represent key ingredients to success in the application of freeway simulation for corridor analysis:

- Understanding the model's application to the objective Freeway simulation modeling is appropriate for some applications and inappropriate for others. The objective Of the Study must be well-defined the MOE's must be specified clearly, and the improvements must be ones to which the model is sensitive.

- Selection of the appropriate simulation model and ancillary analysis tools. The appropriate selection requires an understanding of the strengths and weaknesses of the various models and the application for which they are to be employed. Additional guidance on this subject is provided In chapter 4.

- Attention to detail in the model coding process and ensuing specification of alternatives. The potential for error exists without the analyst being aware of those errors. Double checking the input prior to the validation effort is always recommended. An ability to discern reasonable output from unreasonable output also can help to trace errors.

- Quality input data. Many of the problems associated with simulation modeling and many other analysis efforts can be traced to problems with the data. Although it is a mundane part of the process, the collection of valid data makes the remainder of the process much easier and quicker. Taking shortcuts in data collection may end

up consuming more time rather than less, and may result in disenchantment with the modeling process itself. An agency should not invest in simulation unless it is also prepared to provide reliable data to support the process.

- Understanding how to interpret model output and its implications in formulating and analyzing alternatives.

- Understanding how the alternatives may influence demand and the limitations in simulation modeling for analyzing situations of elastic demand.

- Qualified staff and intermediate reports to management. Management agreement with the validation is particularly important. In addition, management review of the forecasts prior to their use in the model is advisable to prevent having to rerun alternatives or having the results seriously questioned.

CHAPTER 3. DESCRIPTION OF FREEWAY SIMULATION MODELS

CHAPTER 3. DESCRIPTION OF FREEWAY SIMULATION MODELS

As indicated in chapter **2,** there are two basic classes of freeway simulation models: macroscopic and microscopic. The basic distinguishing features of these two classes were described in chapter 2. One of the keys to utilizing the strengths of each modeling approach is to understand the basic operational characteristics and capabilities of each model. The following sections present a description of each model, including its theoretical basis, input data requirements, output options, and special features. A description of the Highway Capacity Software (HCS), a microcomputer implementation of the freeway analysis procedures in the *1985 Highway Capacity Manual* (HCM) is also included. The technical report for this project presents a full evaluation of each of the models and the HCS. The models are discussed in alphabetical order. Tables 1 and 2 indicate the input and output of the three models and the HCM procedures. These will be referred to throughout this discussion.

FREFLO

FREFLO is one of the component models of the FHWA TRAF system. As a macroscopic model, it falls under the umbrella of the CORFLO subsystem, the macroscopic family of models under TRAF. it runs on either an IBM mainframe computer system or on a microcomputer system with at least the following specifications: IBM-compatible 80386 or 89486 processor with math coprocessor, at least 4 megabytes of memory, and ample disk storage. The model and its documentation can be obtained from the FHWA Office of Research, Development, and Technology in McLean,VA.

FREFLO has its origins in the MACK model, developed in the early 1970's. FREFLO uses flow conservation principles and an equilibrium speed-density relationship incorporated into a dynamic speed equation. On 8 of the relationships between speed and density used in the model is shown in figure 5. FREFLO tracks the development and dissipation of traffic queues based on the status at the end of the previously simulated time slice and on the flow input and output in the currently simulated time slice. It can accommodate more than one freeway in a single network and can simulate ramps connecting the two freeway systems. The user defines a freeflow speed, which establishes the upper bound for thespeed estimate.

The input to FREFLO is prepared in card image-type fixed format Figure 6 indicates the required and optional card types. The user must identify the card type and provide the necessary data in the proper columns. Mistakes in the entry of data into the proper columns' wuid resutt In an aborted run or an erroneous simulation. FEDIT is now available to assist the user in data entry (not available during this project). The user manual provides information on error messages, but the problem experienced bythe user is not always readily related to an error message.

A FREFLO subsection is normallly defined as a length of freeway between two ramps. Intermediate sections can also be defined, such as a lane drop or other major geometric change. Capacity is entered as vehicles per hour. On-ramp volume (including the mainline entry point) is entered in vehicles per hour. Off-ramp volumes are specified using "exit fractions," the percentage of traffic leaving the freeway at an exit ramp. This forces a balancing of exit and entry volumes. However, it requires the analyst to conduct a cumulative

Table 1. Freeway simulation model and HCM data requirements.

Data	Model			
	FREFLO	FREQ	FRESIM	HCM
<u>GEOMETRIC</u>				
Link Specific Data On:				
No. Of Lanes	**X**	**X**	**X**	**X**
Length of Section	X	X	X	X
Grade		X	X	
Curve Radius			X	
Parameter Type			X	
Auxiliary Lanes	X	X	X	
Speed-Change Lane Length			X	
Super-Elevation			X	
Lane/Shoulder Width				X
<u>TRAFFIC</u>				
Mainline Entry/Exit Volumes	X	X	X	X
Ramp Volumes	X		X	X
Free Flow Speed	X	X	X	
Capacity		X		
HOV[4] Facilities (optional)	X[2]	X		X
O-D[5] Data (optional)	X	X	X	
Driver Sensitivity (optional)			X	X
<u>CONTROL</u>				
Truck Restrictions			X	
Weaving Restrictions				
Ramp Metering		X[3]	X[3]	
Surveillance			X	
Location of Guide Signs			X	
<u>OPTIONS</u>				
Incidents/Lane Closures	X	X	X	
Constants Equation	X			

[1]Speed flow curves.
[2]Includes modal response.
[3]Several options.
[4]High Occupancy Vehicle (HOV).
[5]Origin-Destination (O-D).

Table 2. Freeway simulation and HCM model output.

Data	Model			
	FREFLO	**FREQ**	**FRESIM**	**HCM**
<u>NETWORK PERFORMANCE MEASURES</u>				
Total Vehicle Miles	X	X	X	
Total Vehicle Minutes	**X**	**X**	**X**	
Average Speed	X	X	X	
Total Minutes Delay		X	X	
Fuel Consumption		X	X	
Emissions		X	X	
Surface Street Performance		X		
<u>LINK SPECIFIC CHARACTERISTICS</u>				
Level of Service	X^1	X^1	X^1	X
Average Volume		**X**	**X**	**X**
Average Density	X		**X**	**X**
Average Speed	X	X		**X**
Queue Length	X^3	**X**	X^3	
Instantaneous			X	
Concentration	X^1	**X**	X^1	**X**
Volume/Capacity (V/C)		X		
Ratio		X		
Spatial Response				
Modal Response				
GRAPHICAL				
Speed Contours	X^2	X	X^2	
Queue Contours		X		
Density Contours	X^2	X	X^2	
V/C Contours		X		
Fuel Contours				
Emission Contours				
<u>OTHER</u>				
Coupled before/after outputs		X		
Metering Plan (optimized)		X		
O/D Trip Tables				

[1] Can be derived from density.
[2] Available using a special routine developed by contractor.
[3] Can be defined if a density threshold is established by the user.
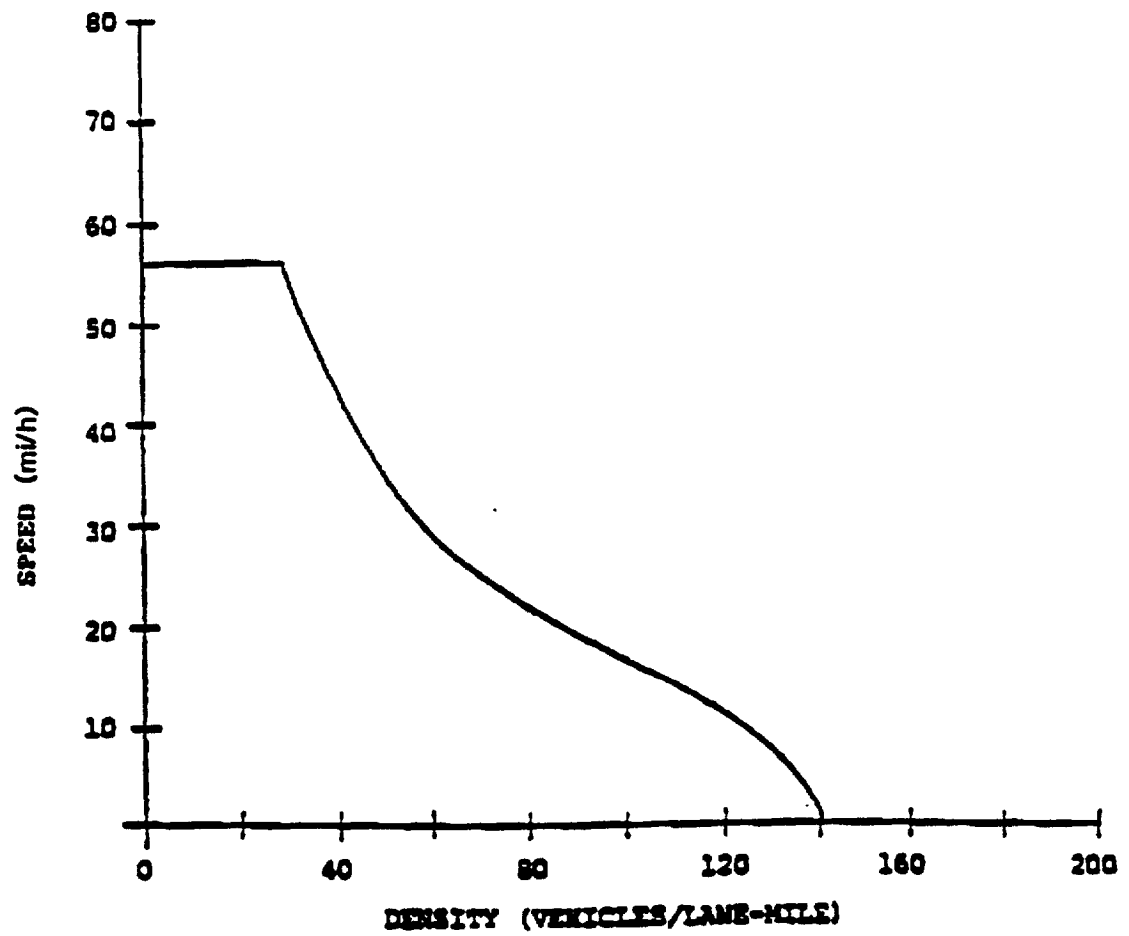
1 mi = 1.61 km
1 mi/h = 1.61 km/h

Figure 5. First equilibrium speed-density relationship used in FREFLO.

Card Type	Description	1st Time Period	Subsequent Time Periods
00	Title	R	N
01	Identification	R	N
02	Run Control	R	N
03	Tie Period Classification	R	N
04	Time-step Control	R	N
05	Output options	R	N
15	Freeway Link Characteristics	R	O
26	Freeway Turning Movements	O	O
27	Freeway Incident Specifications	O	O
34	Freeway Parameters	O	N
50	Entry Link Volumes	O	O
52	Load Factors	O	O
170	Subnetwork Delimiter	R	R
187	Bus Paths	O	N
189	Bus Flow	O	O
210	Time Period Delimiter	R	R

Legend: R = Required; 0 = Optional; N = Not applicable

Figure 6. Input card requirements for FREFLO.

(input/output) volume analysis. Although this is relatively straightforward, it creates inconveniences if, for example, an upstream on-ramp volume should change significantly. This would require complete recalculation of the Cumulative mainline volume and the exit fractions. Spreadsheets are recommended to minimize the work effort involved, particularly the labor required in recalculation if an error is detected. The volume input require a substantially longer time for FREFLO than for FREQ. The user is cautioned against conducting a cumulative volume analysis over too long a section as errors are also cumulative. Additional mainline counts should be conducted to confirm and, if necessary, reset the mainline volume to reduce the cumulative error. These mainline count locations should be on sections that are uncongested throughout the simulation period. Otherwise, the modeler will not be using true demand, but only the capacity-restrained throughput. In addition to volume, capacity can also be modified by time slice, enabling the simulation of traffic incidents and temporary construction/maintenance operations.

In theory, FREFLO could simulate hundreds of miles of freeway using one network and can accommodate many subsections. However, the development of volume data becomes more difficult on simulated sections, and great care must be taken to examine cumulative volumes. One of the shortcomings of macroscopic models is that they have more difficulty dealing with the time/space nature of traffic flow than do microscopic models, because traffic flow must be dealt within aggregate time slices. As part of the CORFLO package, FREFLO networks can be integrated with several levels of arterial simulation, depending on the level of detail required.

Figure 7 shows a typical output format for FREFLO. It reports information for both the end of each time slice as well as a cumulative total for the relevant MOE's. All of the measures are derived from density, volume, and speed. Derivative MOE's include VMT, VHT, and an assortment of other measures, as indicated in table 2. Mainline and ramp statistics are reported by time slice for each subsection (reported by upstream node number to downstream node number). Without subsection labels (not provided by FREFLO), assimilating the results of a run can be time-consuming. A post-processor was written during this contract to convert the FREFLO output to contour diagrams for speed and density. Contour diagrams are quite important in the model validation stage, enabling the user to make a rapid assessment of how well the model matches actual traffic flow.

FREQ

This model was developed at the University of California, Berkeley in the early 1970's and has gone through many upgrades over the years. It was converted to run on IBM-compatible microcomputers in 1989. The most recent version of FREQ is FREQ11. It requires an 80386 processor or higher, a math coprocessor, and 8 megabytes of memory. The memory requirements may be reduced in the future to make the system available to smaller machines. FREQ10 was used on this project. It requires only an 80286 processor and 640k bytes of memory, but the simulated section length and numbers of ramps are more limited (typically 15 mi (24 km)).

```
                                  -   VEHICLE MINUTES      RATIO   MIN./MILE    SEC./VEH.      AVERAGE                           PERSON-MINUTES
                      VEHICLE       MOVE   DELAY   TOTAL   MOVE/  TOTAL DELAY  TOT. DELAY  VOLUME SPEED      PERSON   PERSON     TOTAL     DELAY
          LINK      MILES  TRIPS    TIME   TIME     TIME   TOTAL  TIME   TIME  TIME  TIME    VPH   MPH       MILES    TRIPS      TIME      TIME
          ----      ------------  -------------------- -----  -----------  ----------  -----------      ---------------    ---------------
^        5001,   1)   314.7  3323   290.5     2.0    292.5 0.99    0.9   0.0      5     0   3322  64.5       407.0    4298      377.2       1.5
:           1,   2)  1195.2  3321  1102.3     0.0   1102.3 1.00    0.9   0.0     19     0   3321  65.1      1546.1    4296     1422.1       0.0
:           2,   3)   419.8  2806   387.6     3.2    390.7 0.99    0.9   0.0      8     0   2805  64.5       543.1    3630      504.1       2.8
:           3,   4)   440.8  2387   406.8     0.0    406.8 1.00    0.9   0.0     10     0   2387  65.0       570.2    3088      524.8       0.0
:           4,   5)   123.2  3251   113.7     5.7    119.4 0.95    1.0   0.0      2     0   3251  61.9       159.3    4206      154.0       6.9
:           5,   6)  3629.6  4259  3350.6   187.5   3538.1 0.95    1.0   0.1     49     2   4258  61.6      4695.1    5509     4564.2     230.1
:           6,   7)   745.2  3660   687.9    21.6    709.5 0.97    1.0   0.0     11     0   3660  63.0       964.0    4735      915.3      25.4
:           7,   8)  1774.1  3273  1637.7    18.6   1656.3 0.99    0.9   0.0     30     0   3272  64.3      2294.9    4234     2136.6      18.2
Mainline    8,   9)  2914.5  4231  2690.4   151.6   2841.9 0.95    1.0   0.1     40     2   4231  61.5      3770.0    5473     3666.0     185.9
:           9,  10)  1022.6  1666   944.0    29.1    973.1 0.97    1.0   0.0     35     1   1666  63.1      1322.8    2156     1255.3      34.2
:          10,  11)   849.9  3506   784.6    87.7    872.3 0.90    1.0   0.1     14     1   3506  58.5      1099.5    4535     1125.3     110.4
:          11,  12)   460.7  3041   425.3    26.3    451.5 0.94    1.0   0.1      8     0   3040  61.2       595.9    3933      582.3      32.2
:          12,  13)   876.6  2398   809.2    22.3    831.5 0.97    0.9   0.0     20     0   2398  63.3      1133.9    3102     1072.6      25.9
:          13,  14)   510.0  3025   470.8    23.5    494.2 0.95    1.0   0.0      9     0   3025  61.9       659.7    3914      637.4      28.5
:          14,  15)   307.5  2849   283.9     9.3    293.2 0.97    1.0   0.0      6     0   2848  62.9       397.8    3685      378.2      11.0
:          15,  16)   585.6  3221   540.6    20.8    561.4 0.96    1.0   0.0     10     0   3221  62.6       757.6    4167      724.2      24.9
:          16,  17)   839.2  4084   774.7    46.3    821.0 0.94    1.0   0.1     12     0   4084  61.3      1085.6    5283     1059.1      57.0
:           2,  19)    39.0   515    66.9     0.2     67.0 1.00    1.7   0.0      7     0    516  34.9        50.4     666       86.4       0.0
v           3,  21)    31.9   421    76.4     0.5     76.9 0.99  . 2.4   0.0     10     0    420  24.8        41.2     544       99.3       0.4
^        8020,  20)    65.8   868    87.6     0.0     87.6 1.00    1.3   0.0      6     0    868  45.0        85.1    1123      113.1       0.0
:          20,   4)    65.7   868    87.6     0.0     87.6 1.00    1.3   0.0      6     0    867  45.0        85.0    1122      113.1       0.0
:        8022,  22)    76.5  1010   102.1     0.4    102.4 1.00    1.3   0.0      6     0   1010  44.8        99.0    1307      132.3       0.3
:          22,   5)    76.6  1011   102.1     0.4    102.4 1.00    1.3   0.0      6     0   1010  44.8        99.0    1307      132.3       0.3
:           6,  23)    45.1   595    77.1     0.0     77.1 1.00    1.7   0.0      7     0    595  35.1        58.3     770       99.4       0.0
:           7,  25)    29.2   386    50.0     0.0     50.0 1.00    1.7   0.0      7     0    385  35.1        37.8     499       64.5       0.0
:        8024,  24)    73.1   965    97.5     0.0     97.5 1.00    1.3   0.0      6     0    964  45.0        94.6    1248      125.8       0.0
:          24,   8)    73.1   964    97.4     0.1     97.5 1.00    1.3   0.0      6     0    964  45.0        94.5    1248      125.8       0.0
Ramps       9,  27)   196.0  2561   332.6     0.4    333.0 1.00    1.7   0.0      7     0   2560  35.0       250.9    3313      429.5       0.0
:        8026,  26)   139.4  1840   185.9     0.3    186.1 1.00    1.3   0.0      6     0   1840  44.9       180.3    2380      240.1       0.0
:          26,  10)   139.4  1840   185.8     0.3    186.1 1.00    1.3   0.0      6     0   1839  44.9       180.3    2380      240.1       0.0
:          11,  29)    35.1   464    60.2     0.1     60.3 1.00    1.7   0.0      7     0    463  35.0        45.5     600       77.7       0.0
:          12,  31)    48.5   640    64.7     0.1     64.8 1.00    1.3   0.0      6     0    640  44.9        62.7     828       83.6       0.0
:        8028,  28)    47.9   632    63.6     0.0     63.6 1.00    1.3   0.0      6     0    632  45.2        61.9     818       82.0       0.0
:          28,  13)    47.9   632    63.8     0.1     63.9 1.00    1.3   0.0      6     0    631  44.9        61.9     817       82.3       0.0
:          14,  33)    13.1   173    17.4     0.2     17.7 0.99    1.4   0.0      6     0    172  44.4        16.9     223       22.9       0.3
:        8030,  30)    28.3   373    37.7     0.1     37.8 1.00    1.3   0.0      6     0    373  44.9        36.6     483       48.8       0.0
:          30,  15)    28.3   373    37.7     1.2     38.8 0.97    1.4   0.0      6     0    372  43.6        36.5     482       50.1       1.4
:        8032,  32)    65.6   866    87.5     0.4     87.9 1.00    1.3   0.0      6     0    865  44.8        84.9    1120      113.5       0.4
v          32,  16)    65.6   866    87.4     2.6     90.0 0.97    1.4   0.0      6     0    865  43.7        84.8    1120      116.2       3.2
         SUBNETWORK= 18438.2  9205   296.2    11.0    307.2 0.96    1.0   0.0      2     0         60.0     23850.7   11871     396.30     13.35
                                  ---- VEHICLE-HOURS ----                     MINUTES/                                        PERSON-HOURS
```

1 mi = 1.61 km

1 mi/h = 1.61 km/h

Figure 7. Sample FREFLO output.

Prior to version 10, FREQ operated under two separate submodels, with the suffixes PE (priority entry) and PL (priority lane). Version 11 still incorporates these two submodels, but allows them to operate under the master program, requiring only one data input stream. Versions 10 and 11 have the same data structures.

The input data for FREQ is organized into card image format similar to FREFLO. Input screens are provided in menu-driven format, relieving the user from looking up column numbers and greatly speeding up the data entry process. The freeway geometry can be printed graphically, assisting the user in checking the input data.

FREQ operates on the basis of speed/volume and demand/capacity relationships.   It was first developed based on the relationships in the 1965 *Highway Capacity Manual* (HCM). Speed/volume relationships are used to compute speed for subsections. Several curves are resident in the program, one of which can be selected for any simulation, or a user-developed curve can be specified. Up to nine curves can be stored in the program. The curves resident in the program were derived from multiple sources and can be selected by choosing the appropriate freeflow speed. For most freeways, the default 65 mi/h (104.7 km/h) curve is appropriate. New research on speed/volume relationships is indicating that high speeds are sustained even at high volume/capacity ratios and that speeds drop off precipitously to congested, unstable levels. It is expected that future FREQ versions will include new formulations resulting from additional research.

The development of queues in FREQ is based on comparisons of demand and capacity by subsection and time slice. When demand reaches the capacity defined for the subsection and time slice, a queue begins to form.   FREQ computes the length of the queue on the basis of speed/density relationships and can monitor the collision and splitting of multiple queues through shock wave analysis. In the original versions of FREQ, the model was a literal implementation of the HCM procedures, including the lookup tables for passenger car equivalents, grade factors, etc.   It was found, however, that successful validation of the model required refinement of the capacity values to account for various conditions or for inaccuracies in the HCM-based relationships. Currently, default capacity is defined, and variations to this capacity can be input on a section-by-section basis using information provided by the analyst. This allows greater flexibility, but also places more responsibility on the analyst for choosing values that are appropriate.

FREQ incorporates the weaving analysis procedures and ramp merge/diverge procedures of the 1965 HCM. The 1985 HCM modified the weaving procedures, but did not provide estimates of weaving area capacity. Because FREQ operates on a demand/capacity basis, it could not Incorporate the 1986 weaving procedures. The ramp analysis procedures were unchanged in the 1986 HCM. The user may disable the weaving and ramp analysis procedures, if desired. Because most users have found that the weaving analysis algorithm in the 1965 HCM too severely limits capacity through weaving sections, many users disable the weaving algorithm and supply alternate values. However, it is often useful to have weaving engaged in the initial runs to identify locations where weaving is likely to be a problem. If no weaving problems are identified, this may avoid more detailed scrutiny. Locations with weaving problems can be supplied with alternate capacity values..

The ramp merge/diverge logic evaluates potential problems in the merge lane and flags potential merge/diverge problems. FREQ also accounts for ramp queues on both exit ramps and entry ramps. However, a queue on an off-ramp will not affect mainline flow. Rather, the queues are Stored vertically, without impacting other traffic.

FREQ also allows a parallel arterial roadway to be coded. The parallel arterial is provided to handle traffic diverted to and from the freeway under ramp metering and priority lane analysis, and is not intended to be an analysis tool for arterial operations. The arterial simulation is an approximation that lends to the realism of the decisions drivers may make under ramp metering and HOV lane operations. There is a one-to-one correspondence (in terms of length) between arterial subsections and freeway subsections. The arterial cannot be coded as a separate network with its own section lengths, and the estimation of the effect of signals is relatively crude.

The PE subprogram of FREQ allows the user to test ramp metering options with and without priority entry (i.e., HOV) lanes. A linear programming algorithm allows the model to optimize ramp metering operations in accordance with one of several objective functions. The user may control the metering rates as well as decision criteria that drivers use in determining whether to wait at a ramp or to divert to the arterial. The PE optimization algorithm can take freeway vs. arterial trip time into account in developing its optimization plan. Depending on the options selected, the PE feature can simulate spatial shift criteria (i.e., diversion to the arterial) and modal shift criteria (i.e., the creation of new carpools due to time saving for HOV's at the on-ramps). These shifts have a basis in research on actual operations, but there is still much unknown about driver response under these conditions.

The PL subprogram allows the simulation of a one- or two-lane concurrent flow HOV lane. A two-person-or-more or three-person-or-more carpool threshold can be defined or the lane defined exclusively for buses. The PL program requires that auto occupancy percentages be defined for each on-ramp. Bus load factors must also be specified, or can be defaulted or ignored. The vehicle occupancy values are used to compute person-based measures, such as person miles of travel (PMT) and person hours of travel (PHT). All eligible HOV's are assigned to the HOV lane.

FREQ allows the user to directly input both entry and exit ramp volumes.   Unless the user has pre-balanced the exit volumes to the entry volumes, the total exiting traffic will not equal the total entering traffic.   If the simulation period has been properly selected (Le., beginning prior to congestion and ending after congestion), total Input and output over the course of the simulation will be approximately equal.   However, this is not true for any given time slice, as more vehicles enter than exit when congestion is building and more vehicles exit than enter when congestion is dissipating.   Balancing volumes by time slice could lead to erroneous results. FREQ balances volumes by factoring total destinations (exiting volume) to match total origins (entering volume). The theory is that entry volumes represent true demand, while exit volumes may represent something less than demand during periods when congestion is building, since vehides cannot reach their exits as quickly as they would under freeflow conditions.   In the process of balancing the volumes, FREQ also creates a trip table of trips from each entry origin to each exit destination. This trip table is used to generate weaving volumes for use in the weaving algorithm and in the simulation of traffic diversion. The simulation was found to be a reasonably good approximation when compared with actual freeway origin/destination (O/D) data in two of the case studies. Grades and trucks are input in FREQ, but these are for emissions and noise estimates only and are not used in the

simulation of traffic operations. The user must deal with those effects through the specification of capacity values.

FREQ, output are the most informative and comprehensive of any of the analyzed simulation models. MOE's include VMT, VHT, PMT, PHT, ramp-to-ramp travel time, emissions, noise, and a variety of others.   Output reports can be selected for any model run. Figure 8 shows a typical time slice report from FREQ. It reports subsection number, number of lanes, subsection length, traffic demand based on the origin destination data, traffic volumes as modified based on subsection capacity and unserved volume, freeway capacity, capacity reduction due to weaving (tuned off in the example run shown here), queue length in feet, storage rate (whether a queue is growing or dissipating), volume/capacity ratio, average speed, fuel consumption, and emissions. Several possible MOE's (e.g., density) have not been reported because of the desire to constrain the output to one page of width. Special reports are available for ramp metering, including ramp-by-ramp queue length and delays, O/D traffic diversion, O/D model shifts, and before/after comparisons. The contour diagrams from FREQ are available for speed, density, volume/capacity (v/c) ratio, queues, emissions, and noise.

A typical FREQ run without optimization requires less than 2 min on an 80386 processor. When all optimization and model shift options are used, this lengthens to 20 to 30 min for a typical simulated freeway corridor. Because of the demand/capacity formulation of FREQ, bottlenecks and queue locations are normally well-defined in a FREQ simulation. In FREFLO, the bottlenecks tend to be less distinct and the transitions in speed from section to section less dramatic. Comparisons of actual speed profiles with speed profiles from the two models did not indicate one to be always superior. to the other. In some conditions, FREQ provided the better approximation; in other cases, FREFLO was superior. Thus, it is difficult to state that either is operationally preferable. Much more experience is needed with FREFLO under a variety of conditions to determine how the two models compare.

It was stated in the section on FREFLO that caution should be exercised in simulating sections where the length of the section analyzed is greater than the distance a vehicle can travel at freeflow speed. FREQ 11 partially overcomes this limitation by the introduction of a "tilting" algorithm. This algorithm attempts to account for the time/space relationship of volumes entering at an upstream ramp and reaching a downstream section in a later time slice. At best, this algorithm is an approximation of what occurs in reality. But because macroscopic models deal in blocks of time, there is no way for any algorithm to completely overcome this limitation. There will always be some vehicles that should have been included in a different time slice that were not and vehicles that were not included in a different time slice that should have been. Only the microscopic model, which controls the rate of entry of vehicles and trades eaoh vehicle individually across time slices and across the length of the section can fully accommodate the time/space continuum of traffic flow. As computer power increases, the computational limitations of microscopic models will become less of a concern. But the simulation of origin/destination patterns will still be an inexact science, even with the microscopic models.

FREEWAY PERFORMANCE TABLE

SUB SEC	NO. LNS	SSEC LENGTH	O-D DATA DEMANDS ORG.	DES.	DEN.	ADJUSTED VOLUMES ORG.	DES.	VOL.	FRWY CAP.	WEAVE EFF	QUEUE LENGTH	STORAGE RATE	V/C	SPEED MPH	FUEL MPG	HC GS/VM	CO GS/VM	NOX GS/VM
1	5	10000.	4812.	0.	4812.	4812.	0.	4320.	10000.	0. *	2452.	492.	.43	25.	11.39	4.09	32.31	..80
2	3	560.	0.	0.	4812.	0.	0.	4320	..320.	0.	0.	0.	1.00	36.	18.47	3.31	22.25	3.97
3	4	425.	2676.	0.	7488.	3000.	0.	7320	..40.	0.	0.	0.	.98	41.	17.49	3.08	20.05	..19
4	4	5570.	0.	2684.	7488.	0.	2640.	7444	..40.	0. *	614.	-120.	1.00	37.	17.72	3.30	22.40	..08
5	3	3070.	0.	1432.	4804.	0.	1500.	4800.	5300.	0.	0.	0.	.91	46.	16.18	2.96	19.08	..53
6	2	795.	0.	0.	3372.	0.	0.	3355.	3475.	0.	0.	0.	.97	45.	16.57	2.98	19.23	4.39
7	4	800.	2932.	2924.	6304.	3000.	2953.	6355.	6970.	0.	0.	0.	.91	46.	16.19	2.96	19.09	..52
8	3	1040.	0.	0.	3380.	0.	0.	3402.	5260.	0.	0.	0.	.65	49.	15.63	2.93	18.90	..73
9	3	1180.	896.	0.	4276.	896.	0.	4298.	5265.	0.	0.	0.	.82	47.	15.99	2.95	19 02	..66
10	4	980.	780.	728.	5056.	780.	729.	4897.	7030.	0. *	568.	181.	.70	37.	14.47	3.34	23.25	4.55
11	3	900.	0.	0.	4328.	0.	0.	4168.	5280.	0. **	900.	181.	.79	22.	13.13	..52	35.81	3.98
12	3	2200.	632.	900.	4960.	632.	871.	4800.	4800.	0.	0.	0.	1.00	36.	8.56	3.31	22.25	3.97
13	3	2250.	0.	0.	4060.	0.	0.	3929.	4800.	0.	0.	0.	.82	47.	7.52	2.95	19.02	4.59
14	3	4250.	772.	984.	4832.	772.	958.	4701.	4800.	0.	0.	0.	.98	42.	8.02	3.05	19.79	4.25
15	3	1760.	0.	964.	3848.	0.	938.	3743.	5300.	0.	0.	0.	.71	48.	15.75	2.93	18.94	..68
16	3	1350.	0.	0.	2804.	0.	0.	2804.	4800.	0.	0.	0.	.58	49.	7.31	2.92	18.85	4.78
17	3	1650.	1048.	364.	3932.	1048.	356.	3852.	5235.	0.	0.	0.	.74	48.	15.81	2.94	18.96	..66
18	3	200.	0.	3548.	3548.	0.	3496.	3496.	5270.	0.	0.	0.	.66	49.	15.66	2.93	18.91	..72

TOTAL 38980.   MAX(V/C) = 1 00 AVG = 35. 12 19   3 39 23 81 ...

	CURRENT TIME SLICE		CUMULATIVE VALUES	
FREEWAY TRAVEL TIME =	257. VEH-HRS	323. PASS-HRS	1856. VEH-HRS	2339. PASS-HRS
RAMP/FREEWAY DELAY =	44. VEH-HRS	56. PASS-HRS	336. VEH-HRS	423. PASS-HRS
TOTAL TRAVEL TIME =	301. VEH-HRS	379. PASS-HRS	2192. VEH-HRS	2762. PASS-HRS
TOTAL TRAV DISTANCE =	9013. VEH-MI.	11357. PASS-MI.	69476. VEH-MI.	87560. PASS-MI.
AVERAGE SPEED =	33.11 MPH.		37.43 MPH.	
GASOLINE CONSUMPTION =	765. GALLONS		5947. GALLONS	
HYDROCARBON EMISSION =	35. KILOGRAMS		258. KILOGRAMS	
CARBON MONOXIDE =	260. KILOGRAMS		1917. KILOGRAMS	
NITROUS OXIDES =	41. KILOGRAMS		322. KILOGRAMS	

1 mi = 1.61 km

1 mi/h = 1.61 km/h

Figure 8. Sample time slice output from FREQ.

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FRESIM

FRESIM is an extension of the microscopic freeway simulation model INTRAS, developed under FHWA contract in the early 1980's. INTRAS has been implemented successfully in a number of locations. The model is supported by FHWA, who has distributed copies to some 50 organizations. FRESIM is an extensive reprogramming and enhancement of INTRAS to improve its operational performance make it more user friendly, and enhance portions of its logic dealing with lane-changing behavior, freeway incidents, traffic composition, and other variables. FRESIM is currently undergoing final testing by FHWA. A test version of FRESIM was employed and evaluated in this project since it will become the primary microscopic freeway model distributed FHWA in the near future.

The theoretical underpinnings of car-following theory and other aspects of microscopic simulation are not appropriate for discussion in this report. The reader should refer to texts on this specific subject if more detail is required. it is sufficient to say that three of the primary relationships governing traffic flow within a simulated FRESIM network are the car-following logic, the lane-changing logic and other aspects of gap acceptance.

Vehicles are released into the study section at the mainline entry point and at on-ramps. The vehicles are released according to a probability distribution based on the traffic volumes provided by the user in the input data. Although the actual entry volumes assigned by the model will be approximately equivalent to the input volumes, there will normally be some discrepancies. Upon entry, each vehicle is assigned a destination, a vehicle type, and a driver type. The destinations are assigned based on a gravity model type formulation, with the probabilii of being assigned to a given destination computed based on an accessibility factor (based on entry volume) for each origin, an attraction factor (based on exit volume) for each destination, and a travel function between origin and destination. Vehicle types are assigned stochastically based on the vehicle type distribution input by the user. One of ten driver types is assigned based on a probability distribution. The driver types are primarily distinguished by a mean speed (driver sensitivii) factor. The default factors range from 0.88, representing less aggressive drivers, to 1.12, representing more aggressive drivers.

FRESIM provides a number of powerful and flexible features that permit the evaluation of traffic operational strategies, it provides the capability of simulating ramp metering under several control options (but does not include metering optimization), can define incidents by lane and by begin time and end time (to within 1 second), can locate detectors for either testing incident detection algorithms or reporting volume/occupancy/speed data at user-selected locations, and c a n examine the impact of truck lane restrictions on traffic operations, The traffic operational characteristics of each vehicle are influenced by vertical grade, horizontal curvature, and super-elevation, based relationships developed in prior research. There is an embedded vehicle distribution across freeway lanes that, except for the influence of exiting traffic, assumes that vehicles are distributed equally across lanes. Entering and exiting traffic may bias the distribution toward the entry and exit ramp sides of the freeway. The changing of lanes in preparation to exit is influenced by the placement of guide signs. However, there is much unknown about how guide signs affect drivers' lane positioning for exit, and the model does not take into account the difference between familiar and unfamiliar drivers. The lane configurations that can be simulated in FRESIM are quit flexible, but certain conditions require special coding that are not necessarily literal codings of the freeway network. An interface exists between FRESIM and the optional models in the TRAF family but has not been tested. When it becomes operational, FRESIM network will be able to be

integrated with NETSIM networks and the network of the macroscopic arterial models in CORFLO.

A number of the relationships in FRESIM were calibrated based on digitized second-by-second vehicle movement data acquired by FHWA in a prior research contract. However, there has not been an attempt to validate the model across the range of driver sensitivity factors or across the range of possible geometric conditions. The primary means of calibrating and validating FRESIM is through the adjustment of the driver sensitivity factors, which affects vehicle following distance (K factor). This is the parallel activity to modifying the capacity vaiues for FREFLO and FREQ. There is much to be learned about the behavior of FRESIM under the range of conditions, and the user should be aware that there may be a learning process with each application. But there is also a vast potential for analysis that does not exist with the other models. If the microscopic relationships (e.g., car-following and lane changing) reasonably represent the behavior of individual drivers, there is no reason that FRESIM could not evaluate many combinations of conditions and even be used to develop improved relationships that can be incorporated into highway capacity procedures and macroscopic simulation models. There is also the potential to create animations of the simulated traffic, which would provide users with a powerful visual tool to display alternatives and which would allow further work to be done on improving FRESIM's ability to reasonably simulate traffic flow.

The input data requirements for FRESIM are only slightly more demanding than FREFLO and FREQ..in some ways, settingu up FRESIM is easier than setting Up FREFLO and FREQ because the user does not need to perform manual capacity calculations as part of the input process for FRESIM. FEDIT, an input data processor, is available to assist the user in entering data for FRESIM.

Figure 9 shows a typical output format for FRESIM. The output are the primary area in which FRESIM could be improved to be more useful to the analyst Additional manipulations must be conducted with the data to create meaningful results, and there is a need for subsection summaries (e.g., summary of mainline data separate from ramps).

HIGHWAY CAPACITY SOFTWARE

The Highway Capacity Software (HCS) was developed under FHWA sponsorship as a literal implementation of procedures in the 1985 Highway Capacity Manual (HCM). The procedures are extensively described in the HCM and need not be discussed at length here. The four chapters addressing freeways are: Chapter 3, 'Basic Freeway Segments"; Chapter 4, "Weaving Areas'; Chapter 5, 'Ramps and Ramp Junctions'; and Chapter 6, "Freeway Systems'.

The basic segment analysis accounts for the effects of terrain, specific grades, trucks, width restrictions, and the driver population. The HCS assumes a capacity under ideal conditions of 2,000 passenger cars per hour per lane (pcphpi). Recant research indicates that the capacity of a freeway lane may be 2,200 to 2,300 pcphpi. However, the HCS software does not allow the user to enter values higher than 2,000. This requires that manual calculations be conducted following the computer analysis to more accurately account for actual conditions for freeway sections experiencing higher capacities. The simulation models

CUMULATIVE FRESIM STATISTICS AT TIME 6 20 0

LINK STATISTICS

LINK	VEHICLES IN	OUT	LANE CHNG	CURR CONT	AVG CONT	VEH-MILES	VEH-MIN	SECONDS/VEHICLE TOTAL TIME	MOVE TIME	DELAY TIME	M/T	VEH-MIN/VEH-MILE TOTAL	DELAY	VOLUME VEH/LN/HR	DENSITY VEH/LN-MILE	SPEED MILE/HR	LINK TYPE
(1, 2)	1188	1160	4097	298	59.0	464.3	1180.0	288.8	276.1	12.7	0.96	2.54	0.11	148.	6.3	23.61	FRWY
(2, 3)	1160	1155	757	16	9.0	107.5	179.9	10.7	7.0	3.7	0.66	1.67	0.58	1014.	28.3	35.83	FRWY
(3, 4)	1842	1827	471	27	23.7	147.8	490.1	16.0	5.8	10.2	0.36	3.32	2.11	1773.	98.0	18.09	FRWY
(4, 5)	1827	1727	5354	224	48.2	454.8	991.7	138.0	82.6	55.4	0.60	2.18	0.88	419.	15.2	27.52	FRWY
(5, 6)	1094	1091	963	41	11.3	191.4	225.0	41.0	37.9	3.1	0.92	1.18	0.09	494.	9.7	51.05	FRWY
(6, 7)	721	726	164	1	4.1	70.7	82.3	10.5	9.8	0.7	0.93	1.16	0.08	705.	13.7	51.60	FRWY
(7, 8)	1495	1476	1145	14	8.6	139.4	172.6	11.3	9.9	1.4	0.88	1.24	0.15	1381.	28.5	48.46	FRWY
(8, 9)	871	869	128	11	4.6	81.2	92.5	13.5	12.8	0.7	0.95	1.14	0.06	413.	7.8	52.69	FRWY
(20, 3)	699	687	16	16	10.5	54.0	212.1	17.8	6.3	11.5	0.35	3.92	2.54	1058.	69.2	15.29	RAMP
(5, 22)	633	634	22	2	3.8	48.1	73.5	7.1	6.9	0.3	0.96	1.57	0.06	953.	24.9	38.20	RAMP
(6, 23)	370	370	0	2	2.7	28.2	53.8	8.7	8.4	0.3	0.97	1.91	0.07	1118.	35.5	31.48	RAMP
(57, 7)	771	771	6	6	5.2	60.6	104.8	7.9	7.8	0.1	0.99	1.73	0.01	1201.	34.6	34.70	RAMP
(8, 25)	605	606	17	2	3.2	46.0	64.2	6.3	6.2	0.2	0.97	1.40	0.04	911.	21.2	42.97	RAMP

NETWORK STATISTICS

VEHICLE-MILES = 1894.0, VEHICLE-MINUTES = 3924.4, MOVING/TOTAL TRIP TIME = 0.741,

AVERAGE CONTENT = 194.0, CURRENT CONTENT = 660.0, SPEED(MPH) = 28.96,

TOTAL DELAY (VEH-MIN) = 1017.19, TRAVEL TIME (MIN)/VEH-MILE = 2.07, DELAY TIME (MIN)/ VEH-MILE = 0.54

1 mi = 1.61 km
1 mi/h = 1.61 km/h

Figure 9. Sample FRESIM output.

allow capacity values higher than 2,000 pcphpl. There is also debate about the specific grade effects, particularly for the steeper grades and higher percentages of trucks. Experience with attempts to calibrate and validate FREFLO and FREQ on a significant grade in the Seaffle case study suggested that the capacity reductions on grades were too severe in the HCM. Significant changes have occurred in truck drivertrains, wind resistance and other areas since the time of the research from which the current truck/grade factors were developed. No additional experience was gained in the width restriction factors.

The weaving procedures compute speeds and levels of service for both weaving and nonweaving traffic. An overall weaving section level of service measure can also be computed. The weaving procedures in the 1985 HCM do not provide a weaving area capacity value. Recent research has also shown that there are also other deficiencies in the 1985 HCM weaving procedure. The absence of a capacity value in the *1985 HCM* requires the user of the macroscopic simulation models to use the procedure in the 1965 HCM or to employ another technique. Experience with validation attempts using the weaving algorithm in FREQ (an implementation of the procedure in the 1965 HCM) suggests that the procedure reduces capacity by too great an amount. Chapter 6 of this report provides an alternate set of relationships that appear to provide a more realistic estimate of the capacity reduction effect of weaving areas. However, additional research is needed to better quantify the capacity reductions.

The ramp capacity procedures have not changed since the 1965 HCM. The *HCM* permits the assessment of four ramp-related situations. These are: ramp capacity and level of service on the on-ramp proper, ramp merging analysis, ramp diverge analysis, and ramp capacity and level of service on the off-ramp proper. The HCM user is directed to chapters 9 and 10 for capacity and level of service analysis at the entrance to the on-ramp and the ramp discharge exit Into the surface street system. As the HCM states, "the worst resultant LOS is assumed to govern the overall operation of the section in question." Additional research is needed on capacity at ramp merges.

The HCM chapter on freeway systems presents a systematic procedure for evaluating a length of freeway using the procedures in the previous three chapters. It also presents a simplified procedure for analyzing breakdown conditions and discusses how to address freeway surveillance and control systems, work zones, and HOV lanes in the context of the HCM. In effect, the HCM cannot adequately address congested traffic conditions, since it does not adequately accommodate queuing calculations, and sections are analyzed independently. Its primary use will continue to be as a design tool for freeways that can be built to accommodate traffic at level of service E and better.

CHAPTER 4. SELECTING A SIMULATION MODEL

CHAPTER 4. SELECTING A SIMULATION MODEL

Chapter 2 addressed the question of whether freeway simulation was appropriate as an approach to solving a particular problem or dealing with an analytical task relating to freeway corridor planning, design, and operations. Once it is determined that simulation is an appropriate approach, the most applicable model or models must be selected.

These two decisions can sometimes be interrelated. It may be possible that only one model is capable of delivering the answers sought by the project team. In this case, the appropriateness of the approach is synonymous with the appropriateness of the model. In many cases, though, the project team will have options. Chapter 4 is intended to provide more detailed descriptions of the capabilities of each modeling technique. In doing so, it will give the reader additional insights into the overall approach to simulation.

GENERAL SELECTION CRITERIA

As indicated earlier, there are a number of simulation models that have been developed to address freeway analysis. For purposes of this report, the candidate models for selection include FREFLO, FREQ, *and* FRESIM.[1] The applicability of the freeway procedures in the *1985 Highway Capacity Manual* (HCM) is also discussed.

Each of the models have strengths and weaknesses in dealing with various aspects of the planning, design, and operation of freeways. Table 3 represents a qualitative evaluation of each technique's ability to address specific geometric and operational strategies or situations. It expresses the strengths and weaknesses of each model in evaluatlng the geometric or operational strategy or situation indicated. An understanding of the contents of this figure can help in the model selection process. The geometric or operational strategy/situation is identified on the left side of the figure. The four columns indicate the qualitative rating of each model in addressing each strategy or situation. The rating scale is from 0 (not treated at all) to 5 (excellent representation of the strategy or situation). The rating scale is used by the authors of this report as a general indication of relative model utility. The primary factors considered In this evaluation were the degree to which the model reasonably simulates reality and the ease of application to the given situations.

It should be noted that, while the scale is from 0 to 5, none of the models have been rated 5 on any of the strategies or situations. In the view of the authors, there is room for improvement of the models in virtually all of the areas. The ratings for FRESIM tend to be higher, because it simulates more features directly than either FREQ or FREFLO. However, there are still uncertainties in FRESIM regarding how well it validates to a range in traffic

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[1]FRESIM and INTRAS have many similarities, and there would be parallels in the evaluation of both models. However, this contract did not specifically evaluate INTRAS, and table 3 should not be construed to represent an evaluation-of INTRAS. The reader will need to consult the INTRAS documentation directly.

**Table 3. Qualitative evaluation of each model's ability to
Simulate geometric and operational strategies and situations.**

STRATEGY/SITUATION	FREQ	FREFLO	FRESIM	HCS
A) Freeway Geometrics (major)				
1. Major Lane Addition	4	4	4	4
2. Add HOV Lanes	4	3	not treated	not treated
3. Collector-Distributor Roads	not treated	not treated	3*	not treated
4. Relocate Ramps	4	4	4	4
5. Add Interchanges	4	4	4	4
6. Reconfigure Interchanges	2	2	2	2
7. Narrow Lanes	3*	3*	1*	4
8. Arterial Capacity Improvements	2	1**	3**	not treated
B) Freeway Operations				
1. Guide Signs	not treated	not treated	2	not treated
2. Prohibit Lane Changes	not treated	not treated	2	not treated
3. Close Ramp	4	4	4	4
4. Metering Non-Optimized	3	2*	4	1*
5. Metering Optimized	4	not treated	not treated	not treated
6. HOV Priority at Meters	4	not treated	not treated	not treated
7. Surveillance/Detection	not treated	not treated	3	not treated
8. Incident Management Strategies	3	3	3	not treated
9. Variable Message Signs	1*	1*	1*	not treated
10. Vehicle Mix	2*	2*	4	3
11. Truck Lane Restrictions	not treated	not treated	3	not treated
12. Toll Operations	2*	2*	not treated	not treated
13. Construction Management	3	3	3	Not treated
C) Site-Specific Issues				
1. Accel/Decel Lanes	Not treated	not treated	4	not treated
2. Merge/Diverge Ramp	2*	not treated	4	2
3. Off-Ramp Capacity at Surface Street	not treated	1**	2**	not treated
4. Weaving Section	2	1*	4	3
5. Auxiliary Lanes	3	3	4	3
6. Minor Lane Ext. Add.	4	4	4	4
7. Width Restrictions	3*	3*	1*	4
8. Straighten Curve	1*	1*	4	1*
9. Grades	2*	2*	4	4
10. Super-Elevation	not treated	not treated	4	not treated
11. Ramp Geometry	1*	1*	2	2
12. Left Side/Right Side Ramps	1	not treated	4	3

Notes: * Means that the strategy/situation can be simulated only directly.
 ** Means that the strategy/situation can only be simulated with a supplemental model.
 Rating scale is from 1 (very coarse simulation) to 5 (excellent simulation).
 FRESIM has the greatest potential for achieving "excellent" status on a number of the
 options, but additional testing and refinement is viewed to be necessary to fine-tune
 its operation.

conditions. FRESIM clearly has the highest potential for covering the breadth of strategies and situations, but needs to be tested and validated across a range of geometric and operational situations to build user confidence.

In addition to the ability to simulate certain strategies or situations, there are other considerations that come into play as well, such as:

- Length of the section to be analyzed - FRESIM, practically speaking, can currently simulate sections up to 5 mi (8 km) in length. The macroscopic models can simulate much longer sections and require a fraction of the computer time. The primary limiting factors for FRESIM are the number of vehicles that can be simultaneously tracked (currently 3,000) and the computer time requirements (frequently in excess of 12 h for a heavily congested 5-mi (8 km) section, although this can be reduced with a longer time step, such as 2 s).

- Duration of congestion - For a complete analysis, the simulation should start at least 30-min before congestion begins and end after congestion dissipates, for both the validation and for simulations in the horizon year. FRESIM, while not limited in the number of hours it can simulate, requires processing times proportional to the length of time simulated. If these longer processing times can be tolerated, the duration of congestion may not be an issue.

- Available personnel and computer resources - FREQ tends to be the easiest model to use and is the most understandable. This is followed by FREFLO and FRESIM. The operation of all the models requires wmputer familiarity and an understanding of traffic flow and capacity concepts.

- Project schedule - If data are available, the development of a validated freeway simulation model over a significant length of freeway could conceivably be accomplished in as little as 2 person-months. The simulation of alternatives could be accomplished in one additional person-month, assuming that forecasts are available and alternatives have been defined. FREFLO and FRESIM will require slightly longer schedules than FREQ (primarily a function of user orientation). Ordinarily, additional data collection is needed, and the time estimates listed here are conservative and assume that the user is already familiar with the model.

The following general statements can be made regarding the overall strengths and weakness of each model:

- FREFLO and FREQ (both macroscopic simulation models) are best suited to corridor evaluations covering a considerable length of freeway (5 mi (8 km) or more), with an emphasis on determining the best location for transitioning between the basic number of lanes, computing the effectiveness portion of a cost effectiveness analysis for various geometric alternatives, and evaluating traffic management and traffic control alternatives (such as incident management strategies and ramp metering). A significant weakness in the macroscopic modeling systems is the aggregation of traffic flow into time slices, which requires approximations in tracking queues and computing performance for long sections. FRESIM does not encounter this problem and is actually in a better position than FREFLO and FREQ to simulate longer sections once computational power

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provides the faster processing times that will make simulating long sections more practical.

- FRESIM is a more powerful model for testing detailed freeway design features, with particular emphasis on weaving areas, complex ramp merging areas, grades, and the interaction of these elements with certain traffic management measures. FRESIM would typically not be needed for the more standard geometric situations, in which defining basic lane requirements and the transition points (i.e., where to add or drop a lane) are the primary objectives.

- The HCM procedures would primarily be used for refining the basic number of lanes, similar to the application of FREFLO and FREQ. However, it has no ability to analyze the interactive effects between sections (e.g., the effect of a bottleneck section on upstream sections).

It may also be appropriate to select more than one of the analysis tools to take advantage of the strengths of each model for certain conditions, or for checking results of one against another. This might be done, for example, with the HCM and FRESIM procedures, in which the results of one would be compared against the results of the other for validation purposes, and additional scenarios would be run with FRESIM.

MODELING APPROACH FOR EACH STRATEGY/SITUATION COMBINATION

This section provides both background underlying the evaluation of model capabilities in table 3 and a commentary on how a certain geometric and operational strategies or situations would be simulated using each of the three models and the HCS software. One of three possibilities exists for each combination of simulation model and geometric/operational strategy or situation:

- The strategy/situation can be simulated directly by changing a variable explicitly contained in the model. For example, the addition of a lane is directly accounted for by a change in the number of lanes.

- The strategy/situation can be indirectly simulated by changing an input to the model that does not explicitly represent the strategy/situation. For example, lane and shoulder width are not included as variables in any of the models. However the effect of reduced lane widths could be simulated by adjusting the capacity input to FREQ or FREFLO (or the driver sensitivity factors in FRESIM) to represent the effect of the reduced lane widths. This presumes that the analyst has knowledge of the relationship between lane width and capacity.

- The strategy/situation cannot be simulated. This is designated as "not treated" in table 3.

The following sections present a brief description of the required simulation methodology for analyzing each strategy/situation and provide comments on the ability of that methodology to provide realistic results. It supports the qualitative evaluation in table 3. The discussion is

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organized by type of strategy or situation, under which a brief statement is made regarding each of the three simulation models and the HCM procedures. The strategies are organized in the same order as in table 3, beginning with "freeway geometries."

A. Freeway Corridor Geometrics

1. Number of Basic Lanes

FREFLO: Code in the additional lane. The per-lane capacity value need not be modified unless the addition of the lane affects per-iane capacity. However, there are conditions in which the analyst may find it difficult to establish capacity values based on existing procedures. Additional research is needed to better support macroscopic simulation models in the specification of capacity.

FREQ: Same as FREFLO.

FRESIM: Code in the additional lane. If the added lane affects per-lane capacity, the driver sensitlvii factors would need to be modified to account for this effect.

HCS: Specify the additional lane.

2. HOV Lane or Lanes

FREFLO: Indicate the presence of the HOV lane in the model coding. A "special purpose lane" designation is provided on the link card, and all links over which the HOV lane passes should be so identified. A concurrent median-side HOV lane is assumed. Up to nine special purpose (HOV) lanes are permitted on a freeway link

FREQ: Indicate the beginning and end points of the HOV lane and code in the number of lanes. The per-lane capacity value need not be modified unless the addition of the lane affects per-lane capacity. A concurrent median side HOV lane is assumed. The simulation does not include the weaving effect , of vehicles entering and leaving the HOV lane. One or two HOV lanes can be simulated. Access and egress capability is assumed at each entry/exit ramp. All eligible vehicles are assumed to use the HOV lane, and no HOV vehicles are assigned to the non-HOV lane. This can result in HOV lane volumes that are higher than what may actually occur. The modal response function in FREQ may or may not reasonably estimate the creation of new HOV's. This function may need to be adjusted by urban area and to account for the orientation of the freeway (e.g., radial vs. circumferential), as these and other factors can influence the propensity to shift to HOV's. While the modal response model is only an estimate, nevertheless there is an attempt to include it either by selecting imbedded parameter values or the user can input their own modal response parameters. The capacity of the

non-HOV lanes can be automatically reduced due to the HOV vehicles crossing into and out of the HOV lanes.

FRESIM: Cannot be simulated in conjunction with the regular lanes. However, it is possible to simulate individual elements of HOV operation. For example, vehicle operation on an HOV lane upgrade or the effect of weaving from an HOV lane exit to a nearby exit ramp (or entrance ramp to HOV lane entry point) could be examined. However, the simulation would not recognize the vehicles as HOV's, only as vehicles.

HCS: Cannot analyze HOV lanes. However, the vehicle operational effects of HOV lanes at entry and exit points can possibly be examined.

3. Collector/Distributor (C-D) Roads

FREFLO: Cannot simulate the C-D road. Can only reflect C-D road exit and entry points as off-ramps and on-ramps (i.e., only simulates the mainline).

FREQ: Cannot simulate the C-D road. Can only reflect C-D road exit and entry points as off-ramps and on-ramps (i.e., only simulates the mainline).

FRESIM: User can specify a barrier between lanes that would act as a separator for a C-D road. Alternatively, a separate parallel freeway link could be coded.

HCS: HCS procedures could be used to analyze weaving areas on the C-D road separately from the mainline. However, procedures may not be available to accommodate certain situations of weaving area length and numbers of lanes.

4. Basic Ramps Spring

FREFLO: Ramp would be removed from one location and added in another. If the change is minor (i.e., short move upstream or downstream), only the distances need to be changed. A significant change in ramp access would need to include a re-analysis of ramp volume distributions. Major volume changes could require recalculation of all the exit fractions downstream from the relocated ramps.

FREQ: Ramp would be removed from one location and added in another. If the change is minor (i.e., short move upstream or downstream), only the distances need to be changed. A significant change in ramp access points would need to include a re-analysis of ramp volume distributions. The origin/destination (O/D) simulation routine in FREQ would redistribute and balance on-ramp and off-ramp volumes.

FRESIM:　　Ramp would be removed from one location and added in another. If the change is minor (i.e., short move upstream or downstream), only the distances need to be changed. A significant change in ramp access would need to include a re-analysis of ramp volume distributions. Major volume changes could require recalculation of all the exit fractions downstream from the relocated ramps.

HCS:　　Analysis would need to account for volume changes and would use new section lengths. Ramp procedures were based on very limited data and are in need of additional research. This also affects operation of the macroscopic models.

5. Add Interchanges

FREFLO:　　New ramps and section lengths would be coded. New volumes would be estimated and exit fractions computed.

FREQ:　　New ramps and section lengths would be coded. New volumes would be estimated and coded into the model. FREQ O/D algorithm would balance and recompute volumes. New volumes should be checked for logical consistency with pre-interchange volumes. The O/D simulation may cause some of the upstream and downstream exit ramp volumes to change.

FRESIM:　　New ramps and section lengths would be coded. New volumes would be estimated and exit fractions computed.

HCS:　　Procedures would need to account for volume changes and would use new section lengths. [See other comments on weaving and ramp capacity in other sections]

6. Reconfigure Interchanges/Relocate Ramps

Same processes as in A4 for all models. The geometry of the ramps cannot be simulated with FREFLO or FREQ. While ramp geometry can be coded into FRESIM, . the results are relatively untested. FRESIM may eventually be a tool for examining ramp capacities under various interchange configurations, and is better equipped to analyze weaving and merging than the macroscopic models.

7. Narrow Lanes (With Lane Addition)

FREFLO:　　Indirect simulation. Specify additional lane and adjust per-lane capacity value to coincide with the effect of reduced lane width. Factors can be developed from the HCM. However, lifflsinformation is available for making a definitive estimate of capacity for narrow lanes.

FREQ: Same process as FREFLO.

FRESIM: Specify additional lane and adjust driver sensitivity factors to account for change in capacity. This adjustment would need to be validated against a known capacity change, as the relationship between driver sensitivity factors and capacity is uncertain.

HCS: A modified maximum service flow rate would be selected to account for the effect of reduced width. However, there is only limited data on differences in capacity by lane and shoulder width.

8. Arterial Capacity

FREFLO: Effect on the freeway would have to be determined by estimating volume that may shift to the arterial. Arterial would be simulated through interconnected networks with other models in TRAF package (CORFLO level 1, CORFLO level 2 and NETSIM)

FREQ: Effect on the freeway would have to be determined by estimating volume that may shift to the arterial. FREQ can simulate arterial operation, but simulation is crude in comparison with other arterial models currently available. The arterial is primarily designed to serve as a receptor and source for demand shifts between the freeway and arterial under ramp metering optimization and for estimating model shifts for HOV strategies. There is at least an attempt to begin to look at the freeway on a corridor basis. Traffic diversion from the arterial to the freeway can also be analyzed when HOV lanes are added to the freeway.

FRESIM: For FRESIM, the effect on the freeway would have to be determined by estimating volume that may shift to the arterial. Interconnection with arterial models will be available in the future, allowing full integrated freeway/arterial simulations.

HCS: Arterial and signalized intersection procedures would be applied, independently from the freeway procedures.

B. Freeway Corridor Operations

1. Guide Signs

FREFLO: Operation is not influenced by guide signs.

FREQ: Operation is not influenced by guide signs.

FRESIM: Uses guide signs to influence decisions by drivers to change lanes in preparation for exiting. Does not account for familiar vs. unfamiliar drivers, and driver response to guide signs is not well understood. Should not be used-to establish guide sign placement. Experience indicates that guide signs need to be placed farther upstream in the simulated section than their actual placement on the freeway to achieve proper lane changing behavior. Otherwise a high proportion of simulated vehicles may miss their exits.

HCS: Operation is not influenced by guide signs.

2. Prohibit Lane Changes (e.g., to solve a weaving problem)

FREFLO: The prohibition wouid create two separate sections with two separate capacities and volumes, a situation that cannot be handled by the model. Although it may be possible to modify capacity to account for the effect of the lane change prohibition (i.e. lack of weaving), there is no empirical basis for making this decision.

FREQ: Same as FREFLO.

FRESIM: The lane barrier capability of FRESIM could be used to block lane-changing in a specified area. Volumes from on-ramps and exit fractions to off-ramps would have to be specified accordingly.

HCS: The HCM procedures would need to be applied separately to lanes on each side of the prohibition.It is uncertain whether the HCM would address all resulting configurations (depends on barrier location).

3. Close Ramp

FREFLO: Volumes would have to be redistributed in response to the closure. Some of the volume would likeiy use other ramps.   New exit fractions wouid have to be computed. Accuracy of effect on mainline operation is dependent on ramp capacity procedures from HCM, which require additional research.

FREQ: Volumes would have to be redistributed in response to the closure. Some of the volume would be likely to use other ramps. New O/D patterns would be estimated using the O/D simulation algorithm. Accuracy of effect on mainline operation is dependent on ramp capacity procedures from HCM, which require addiional research.

FRESIM: Volumes wouid have to be redistributed in response to the closure. Some of the volume would likely use other ramps.   New exit fractions would have to be computed. New O/D patterns would be estimated using the O/D simulation algorithm.

HCS: The procedures would be applied to the new volumes and ramp configurations.

4. Metering, User-Defined Without HOV Bypass

FREFLO: The model has no metering capability. Fixed-time metering can be approximated using ramp capacities equivalent to the metering rate. Ramp capacities may be varied by time slice. No driver response is built into the model.

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FREQ: Fiied metering rates can be established, with options for on-ramp motorists to divert to the arterial based on a user-specified set of decision criteria. Considers metering only as aggregate demand reduction on freeway mainline. Does not consider effect of metering on merging operation.

FRESIM: Several metering types can be selected, including fixed time. Considers both effect of limiting demand and on-ramp merging operations.

HCS: Does not accommodate ramp metering. Analyzes only one section at a time.

5. Metering, Optimized

FREFLO: Not treated.

FREQ: Uses linear programming to generate a corridor optimum. User can set maximum and minimum rates as well as decision criteria for drivers to divert from on-ramps to the arterial. Objective functions include maximizing vehicle or vehicle-miles of travel for normal entry control and maximizing person or person-miles of travel for priority entry control. Other constraints that can be entered include maximum v/c ratio at bottlenecks, maximum queue lengths at each ramp, and designation of ramps which are not to be controlled. By setting maximum and minimum metering rates for various ramps in various time slices both at the same value, the user can enter their own ramp metering pm.

FRESIM: Generates a local optimum based on mainline demand/capacity relationships or gap acceptance logic.

HCS: Not treated.

6. Metering, HOV Priority

FREFLO: Not treated.

FREQ: incorporates a modal shift algorithm that generates additional HOV's in response to the delay saved by HOV's at the on-ramps. Algorithm calibrated for specific locations in California. Modal shift responsiveness may need to be modified depending on the nature of the urban area and orientation of the freeway. However, the effect of violation rates by altering the percentages of HOV and non-HOV vehicles at the entry ramp.

FRESIM: No HOV priority capability.

HCS: Not treated.

7. Traffic Surveillance/Incident Detection

FREFLO: Not treated.

FREQ: Not treated.

FRESIM: Includes capability to place detectors at user-specified locations. incident detection algorithms can be formulated and tested using the detector locations.

HCS: Not treated.

8. Incident Management Strategies

Comment: Incident management strategies primarily involve measures to reduce the time for detecting, responding to and clearing incidents from the freeway. Examples include freeway service patrols and freeway surveillance/detection. The primary objective in evaluating incident management strategies is typically estimating the delay savings that can be achieved with the recommended strategies. Steps may include:

- Model coding and calibration/validation to non-incident conditions.

- Estimate incident frequencies, durations, and locations of occurrence.

- Simulate the corridor under a series of typical incidents. Figure 10 shows typical queue contours that would be produced, illustrated from the New York case study.
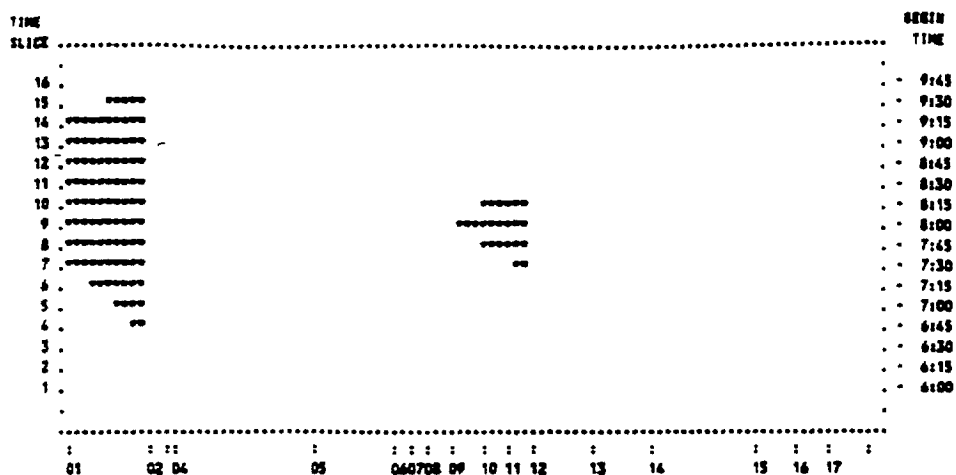
No Incident
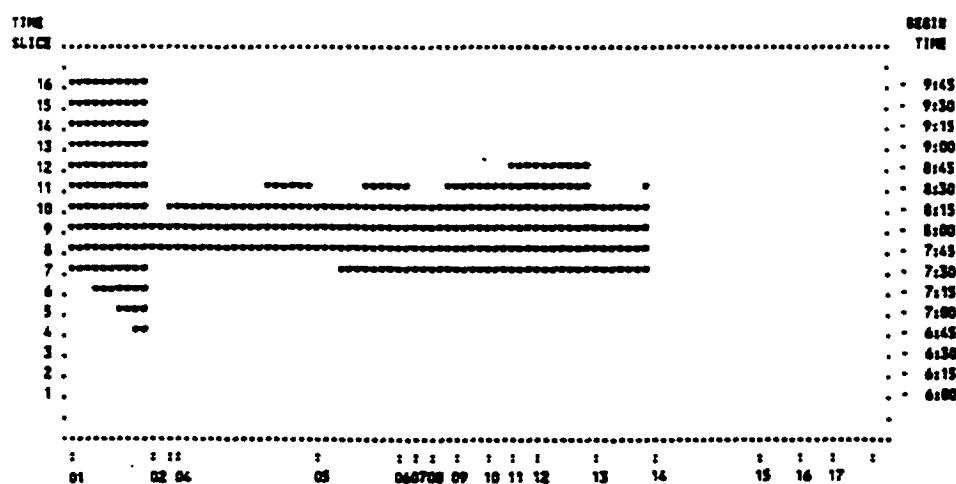
30-Minute Incident (plus 15 Minutes on Shoulder)

Incident Location
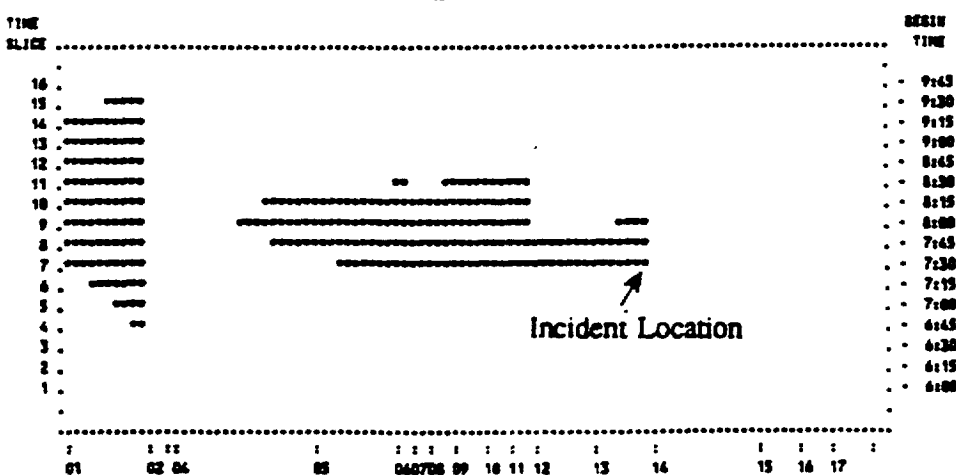
15-Minute Incident

Source: New York case study

Figure 10. Sample comparison of queue contour diagrams
for incident and non-incident conditions.

Construct a relationship between delay or vehicle hours of travel and incident duration for each incident location and seventy combination simulated. Figure 11 shows an example from the case study in New York for a single lane incident on a three-lane freeway. A simulation would be run with incidents of 0 duration, 15 min duration, 30-min duration, 45-min duration, etc., until a full curve had been generated (up to 90-min - most models will not be able to handle longer incidents).

- Estimate the total average incident duration that is predicted to occur with and without the additional incident management strategies.

- Enter figure 11 (will be unique to each project) with the duration of incident with and without the strategy being evaluated. The difference between the delays or vehicle hours of travel (VHT) values is the quantity of delay saved per average incident. Estimate the delay savings for a series of typical incidents and extrapolate the result to an estimate of annual delay savings.

- If a cost-effectiveness analysis is being performed, compare the reductions in delay accomplished by reducing incident duration against the estimated costs for the improvements.

There are other queue and delay estimation methodologies and software available. However, these greatly simplify traffic flow, considering the freeway only as a tube with one entry point and one exit point and will provide only a basic estimate of incident delay. A simulation model will provide a more exact estimate. However, even a simulation model does not account for driver response to the incident conditions (i.e., upstream traffic demand may change when drivers hear of the incident or experience severe congestion). Simulation models assume that demand will stay constant with or without the incident. Thus, they tend to estimate a maximum probable delay savings. In this context, the following approaches are appropriate for the simulation models.

FREFLO: Specify the time slices during which the incident is to be active and code in the reduced capacity for those time slices.

FREQ: Specify the reduced capacity in the "reduced capacities" option for all time slices affected by the incident (e.g., a 45-min incident would affect three 15-min time slices).

FRESIM: Indicate the beginning and ending times for the incident and the lane or lanes blocked. In FRESIM, the beginning and ending times of the incident may be indicated to the minute and second and do not need to coincide with time slices, a limitation that exists in FREFLO and FREQ. FRESIM also allows the simulation of an incident warning sign. This influences drivers to shift out of the incident lane earlier than they would otherwise.

HCS: Not treated.
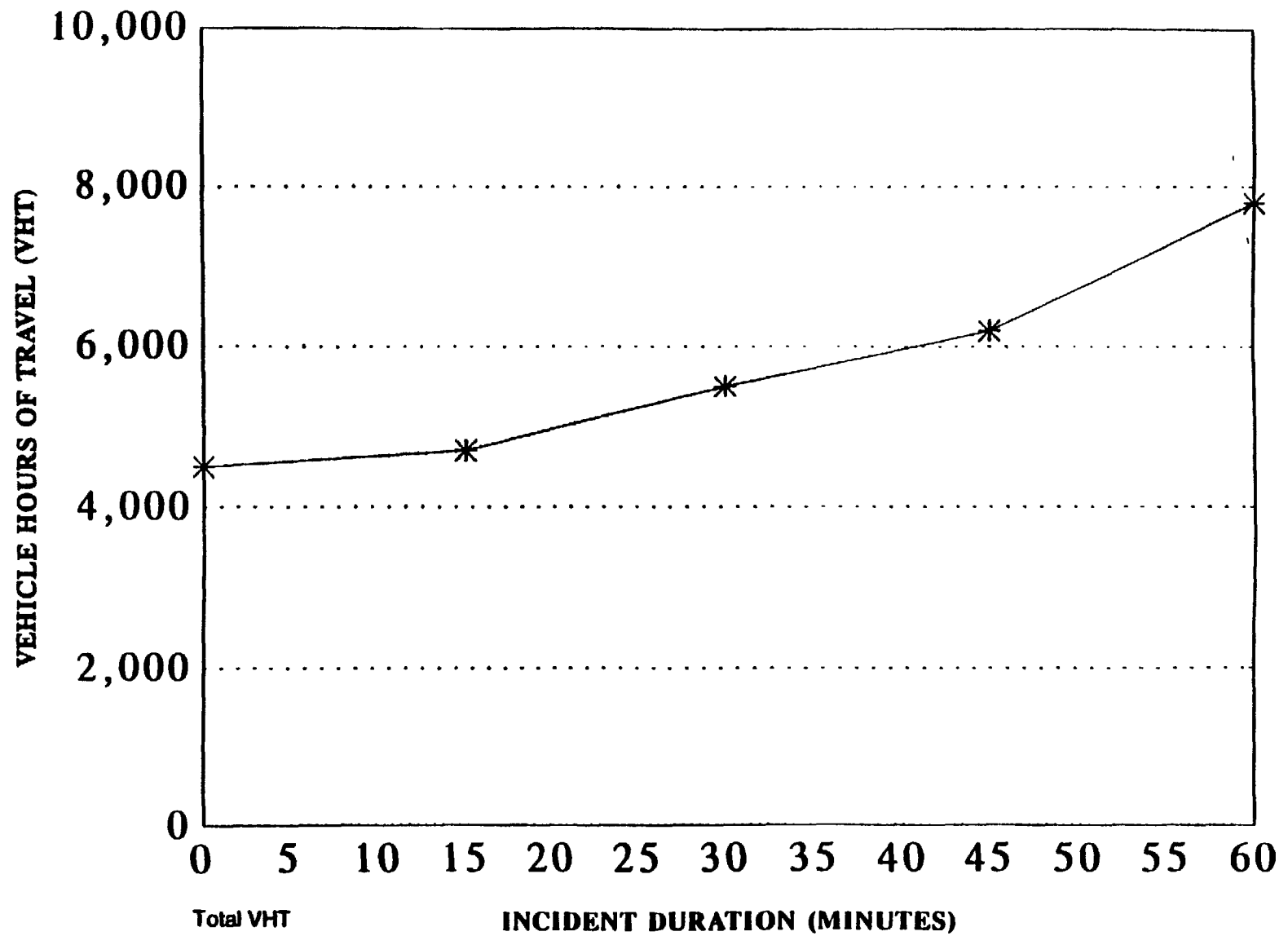
Figure 11. Relationship between vehicle hours of travel and incident duration generated from simulation results in New York case study (single lane incident on Cross Bronx Expressway).

9. Variable Message Signs (diversion strategies)

FREFLO: Motorist response to variable message signs and diversion strategies would need to be reflected in manual volume adjustments to on-ramps and off-ramps in the simulation model. Little basis exists for estimating diversion percentages, and separate estimates would need to be made for the effect on the arterial.

FREQ: Same as for FREFLO.

FRESIM: Same as for FREFLO for route diversion. FRESIM simulates incident warning signs and lane diversion, as discussed above.

HCS: Not treated.

10. Changes in Vehicle Mix

FREFLO: Uses no truck traffic specifications. Changes in mix would need to be reflected indirectly in the calculations of capacity.

FREQ: User specifies percentage of trucks. However, truck percentage is used only in the emissions estimation. it does not influence traffic operations, as it is assumed that the user will account for this in the capacity calculations.

FRESIM: Percentage of trucks is input by the user and is a key factor in vehicle operations, particularly in the assessment of grade effects.

HCS: Percentage of trucks is an important factor in most of the freeway procedures. Additional research is needed to update the truck/grade procedures.

11. Truck Lane Restrictions

FREFLO: Could be accommodated only very indirectly through changes in capacity to account for the operational effects of the restriction, if any.

FREQ: Same as FREFLO

FRESIM: Trucks may be restricted to a user-specified number of lanes on either right or left side of the freeway (e.g. the right two lanes of a four lane freeway).

HCS: Could be accommodated only very indirectly through changes in capacity to account for the operational effects of the restriction, if any.

12. Modify Toil Operations

      FREFLO: Toil plazas could be specified as a block of capacity on the mainline based on the maximum toil processing rate for all the gates. The effect of changes in toil operations (e.g., increasing toil processing rate through automatic vehicle identification) could be estimated by changing the capacity.

      FREQ: Same as FREFLO.

      FRESIM: FRESIM could simulate toil operations through its mainline metering capability, although this routine has not been debugged at the present time.

      HCS: Not treated.

13. Traffic Control During Construction

      FREFLO: Could estimate potential impact of construction by changing capacity. Volume redistribution, if expected, would need to be accommodated manually. Short maintenance interruption could be simulated by specifying capacity reductions only for certain time slices, similar to the method described for simulating incidents.

      FREQ: Same as FREFLO.

      FRESIM: User may specify the duration of lane closures, when the closure begins, and which lanes are to be dosed. Warning sign capability can be used to test effectiveness for upstream traffic to position itself in advance of the closure.

      HCS: Chapter 6 of the HCM contains procedures for estimating queue length, with specific application to construction zones. However, thii calculation considers the mainline only and does not factor in the effect of upstream on-ramps and off-ramps.

c. Site-Specific Features

1. Acceleration/Decleration Lanes

      FREFLO: Not treated.

      FREQ: Not treated.

      FRESIM: User must specify acceleration/deceleration lane length. Lengths of lanes can be tested to determine most appropriate length.

HCS: Not treated.

2. Ramp Merge/Diverge Operations

FREFLO: Capacity can be calculated based on HCM procedures and used in
            appropriate section.

FREQ: Uses HCM procedure for merging/diverging. This logic can be turned off
            and on by the user.

FRESIM: Addressed through lane changing, car-following, and gap acceptance logic in
            the model.

HCS: Provides procedures in Chapter 5 of HCM.

3. Off-Ramp Capacity Problem at Surface Street Affecting Mainline Traffic

FREFLO: If arterial is not simulated, reduce capacity on the off-ramp to the point
            where it approximates capacity of the off-ramp at the intersection with the
            surface street. if arterial is being simulated along with FREFLO, off-ramp
            queue effect will be accounted for.

FREQ: Reduce capacity on the off-ramp to the point where it approximates capacity
            of the off-ramp at the intersection with the surface street. The queue from
            an off-ramp capacity problem will not affect the mainline in FREQ. To model
            the influence of the off-ramp queue, a new mainline capacity would need to
            be used, estimating the degree to which the off-ramp actually influenced
            mainline capacity. However, this is quite difficult and unreliable.

FRESIM: Will be able to accommodate off-ramp capacity constraint when integrated
            with arterial models in TRAF.

HCS: The potential affect cannot be evaluated through the HCS software since the
            signalized intersection software (HCM chapter 9) cannot analyze
            oversaturated conditions. However, other queue estimation methods could
            possibly be used to determine whether the capacity problem will result in a
            queue backing onto the freeway from the surface street.

4. Weaving Section

FREFLO: FREFLO cannot directly analyze a weaving section. it relies on a weaving
            capacity to be input by the user.

FREQ: FREQ contains a weaving analysis algorithm based on the procedure in the 1965 HCM (the 1985 HCM does not provide a capacity value as an output). Experience with the model indicates that the procedure often overestimates the capacity-reducing effect of weaving traffic. Therefore, an alternate value is usally needed for input from the user (see chapter 6). The weaving analysis procedure can be enabled or disabled at the discretion of the user.

FRESIM: This is potentially the most powerful analytical capability of FRESIM. However, the algorithm has not been thoroughly validated against field data. The weaving analysis requires no special input, but is analyzed in the course of the simulation through car-following, gap acceptance, and lane changing logic.

HCS: The level of service for weaving sections can be directly analyzed with HCS. However, there is continuing debate over the accuracy of those procedures and additional research is needed.

5. Auxiliary Lanes

FREFLO: An additional lane and added capacity are coded into the network However, the user must be careful to make appropriate adjustments to. account for weaving and other complex maneuvers either introduced or tempered through the use of the auxiliary lane. The weakness in the HCM procedures for weaving have been referred to previously.

FREQ: Same process as FREFLO.

FRESIM: An additional lane is coded into the network. FRESIM does not require special capacity adjustments to account for weaving, if that is an issue in the section. FRESIM cannot make adjustmsnts to the driver sensitivity factors on a section-by-section basis. if special circumstances require additional adjustments to better simulate a given subsection (e.g. narrow lanes and shoulders), FRESIM's rubbernecking factor wuld be used. This wouid create a user-specified reduction in capacity limited to that section.

HCS: An additional lane is added and other capacity/se&e volume adjustments. are made according to the procedures.

6. Minor Lane Extension/Addition

FREFLO: The section length would be respecified to account for the additional length. However, the effect on traffic operation would depend on the user input of capacity for that section which presumably, would be part of the reason for the lane extension. The weaknesses in the HCM weaving/merging procedures may limit the accuracy of this analysis.

FREQ: The section lengths would be modified to account for the change in lane length. Possibly, the ramp merging or weaving logic (based on the procedures in the HCM) would account for this affect on traffic operation. As discussed previously, however, these affects may not be accurately portrayed in the HCM procedures.

FRESIM: The lanaextension would be reflected in the new section lengths coded into the model. FRESIM should directly account for the change in traffic operation through its car-following, lane changing, and gap acceptance logic.

HCS: The affect on traffic operation would be accounted for through the procedures, based on modified section lengths.

7. Spot Width Restrictions

FREFLO: Modifications would be made in the section capacity value to account for the effect of the width restriction (assumed to be spot restrictions, rather than reduced lane widths over a long section). Factors contained in the HCM procedures require additional research.

FREQ: Same process as FREFLO.

FRESIM: The effect on width would have to be accounted for by modification of the driver sensitivity factors or rubbernecking factor. This can be a difficult process, since the relationship between driver sensitivity factors and capacity is uncertain. A validation process would be needed to make these adjustments.

HCS: The effect would have to be indirectly accounted for, as the HCS procedures do not have updated factors for width restrictions. More research is needed. Current NCHRP project may provide additional information.

8. Straighten Curve

FREFLO: The effect would be indirectly accounted for through modifications to capacity. However, the effect of curves on capacity has received limited study, and the relationship is uncertain.

FREQ: Same process as FREFLO.

FRESIM: Current effect would need to be accounted for by rubbernecking factor. Treatment of curves in FRESIM only includes a cap on free flow speed. FRESIM directly accounts for the effect of degree of curvature and super-elevation on traffic operation.

HCS: The HCS software does not account for the effect of horizontal curves. it would have to be addressed indirectly.

9. Grades

FREFLO: The effect of grades on traffic operation would be accommodated through a capacity value computed from the HCM procedures. However, additional research is needed to update and improve the factors to better account for the full range of grade/vehicle mix combinations.

FREQ: Same process as FREFLO.

FRESIM: The effect of grades is directly accounted for in FRESIM, primarily through the car-following logic. However, for any given simulation activity, the results should be validated to an existing condition, with adjustments to driver sensitivity factors to improve the accuracy of the simulation where necessary.

HCS: The HCS software accounts for the effect of grades in several ways. It can generally account for grades through the specification of terrain. However, for urban freeways, the procedures relating to specific grades should be used. See comment under FREFLO regarding need for additional research.

10. Super-elevation

FREFLO: Cannot be simulated.

FREQ: Cannot be simulated.

FRESIM: Super-elevation is an input of the user. FRESIM accounts for traffic operation directly based on the combination of curve radius and super-elevation.

HCS: The HCM procedures do not address changes in super-elevation.

11. Ramp Geometry

FREFLO: One-lane and two-lane ramps can be accommodated by modifying lane specifications and capacity on the ramp. However, curvature is not addressed, and the effect of geometry on on-ramps would have to be accommodated through capacity values input by the user.

FREQ: Same process as FREFLO.

FRESIM: Numbers of lanes are specified directly by the user (one- or two-lane ramps). FRESIM can evaluate traffic operation on ramps in a limited way based on horizontal curvature, vertical grade, and super-elevation.

HCS: Can accommodate ramp configurations up to two lanes.

12. Left Side/Right Side Ramps

FREFLO: FREFLO does not distinguish whether the ramp is on the left side or right side. The user would be required to calculate capacity to account for the ramp characteristics, including side of the freeway with respect to other ramps and volume on each ramp.

FREQ: FREQ does require specification of left side and right side ramps, and accounts for some of the effect (depending on the situation) in the ramp merging and weaving logic. However, there are still precautions that the user should exercise in reliance on those procedures.

FRESIM: Left side and right side ramps are specified, and FRESIM accounts for weaving maneuvers and merging through the car-following, lane changing, and gap acceptance logic. FRESIM treats merging operations the same for left side and right side ramps. However, the differences in traffic operational characteristics between the left side and right side (e.g. more trucks on the right side) will produce differences in merging operation. Reflection of differences in gap acceptance characteristics would require additional research. In addition, the operational effect is heavily dependent on the origin and destination of entry and exit ramp volumes. Although FRESIM predicts O/D interchanges, the user may need to override certain interchanges to more accurately reflect actual traffic characteristics. This is particularly true when dealing with left side and right side ramp combinations.

HCS: The merging and weaving procedures in the HCS software account for left side and right side ramps. The validity of this procedure is uncertain. Again, the accuracy of the results is heavily dependent on having a good estimate of O/D interchanges.

SUMMARY OF GUIDANCE FOR MODEL SELECTION

The preceding sections have presented both overall and situation-by-situation information on the capabilities and limitations of FREFLO, FREQ, FRESIM, and the HCM procedures. Except for FRESIM, all the methods are dependent on the HCM procedures to derive capacity values. However, the validation process for FREFLO and FREQ allows the user to fine-tune capacity estimates and verify model input, providing the level of confidence needed for the study to proceed.

There is no scientific process that can be described for model selection. The decision can be made with several hours of study of this material and perhaps consultation with others having experience in freeway simulation modeling. However, ail those with an interest in the decision, including managers and computer-literate potential users, should be involved in the decision. The issues discussed previously in this chapter should be included as discussion items. These include:

- Length of section to be analyzed.

- Duration of congestion.

- Available personnel and computer resources.

- Project schedule.

- Specific objectives of the proposed study.

- Capabilities of each model to conduct the necessary analyses.

- Documentation of each model, if more detailed questions must be answered on the capabilities of the models for specific combinations of conditions.

An inventory of this information should be assembled for the meeting at which the decision is to be made. The information presented earlier in this chapter should help to weigh the pros and cons of each.

It should also be noted that, for some situations, a travel demand forecasting model will be the appropriate tool, and that simulation models will not be required. For example, the following situations would not be amenable for analysis by a simulation model:

- Evaluation of the spatial shifts in demand in response to an increase in freeway capacity. For example, the addition of one or two lanes to an existing freeway can have significant effects on the routes traffic will use to take advantage of that additional capacity. Traffic may be shifted from parallel arterials or freeways to the improved freeway. If the existing facility is currently congested, possible results could be substantial changes in traffic patterns throughout the subregion as the additional capacity is consumed and changes occur in peaking characteristics. Existing freeway simulation models are not equipped to comprehensively analyze shifts in demand among alternate facilities.

- Modal shifts in response to a change in highway capacity or transit service. Of the simulation models, only FREQ has incorporated a modal shift capability for high occupancy vehicle strategies (HOV lanes and ramp meter bypass for HOV). The modal shifts are based primarily on the travel time differential between the HOV and Non-HOV lanes. However, modal shifts are typically more complex, and require the analysis of additional variables.

- Assessment of regional or subregional impact brought about by changes in demand. For example, the analysis of changes in emissions will normally require a travel demand forecasting model linked with an emissions analysis model. However, the primary weakness of a travel demand forecasting model is its inability to take into account specific geometric conditions in determining the design requirements for a freeway. For example, it could only grossly consider the influence of grades, weaving sections, and bottleneck conditions in terms of their impact on traffic flow. Simply using the volume/capacity ratio from a travel demand forecasting model is not a sufficient basis for freeway design, even if the forecast is for a peak hour. The travel demand forecasting models are best at

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producing input for use in the simulation and in suggesting the required basic number of lanes in a freeway corridor overall. The estimation of lane requirements from a travel demand forecasting model will be primarily in terms of general rules of thumb, based on assumed maximum hourly capacities (e.g., 2,200 vehicles per hour per lane for a high design type facility).

An additional aspect of the relationship between freeway simulation models and travel demand forecasting models is that the simulation models may be called upon to provide better estimates of speed for iterating back through the trip distribution or assignment and for improving estimates of emissions. This iterative concept is in its infancy, and has not even undergone significant tests at this point. However, it is an emerging area of model development.

CHAPTER 5. FREEWAY CORRIDOR IMPROVEMENT STRATEGIES

CHAPTER 5. FREEWAY CORRIDOR IMPROVEMENT STRATEGIES

PURPOSE AND SCOPE

This chapter discusses the process of identifying and selecting appropriate corridor improvements. The discussion is structured around the framework of the corridor analysis process previously shown in figure 2. The scope of the discussion will be limited to the identification of problems in a corridor, their association with possible causes, and the identification and selection of appropriate strategies for corridor improvement. The key tasks in the overall corridor analysis process related to this activity are tasks 12, 13, 22, and 23. The discussion in this chapter, while including references to arterial improvements, is oriented toward the freeway. Reference is made to other facilities in a corridor only as they are connected specifically to a freeway problem.

IMPROVEMENT STRATEGIES IN THE CONTEXT OF THE PROJECT DEVELOPMENT PROCESS

The project development process in figure 2 identifies two time elements for which problems are identified. Current operations are analyzed in task 12 to determine problems for the existing condition. Future operations are analyzed in task 22 to anticipate further exacerbation due to the growth of traffic or other expected changes due to committed actions.

The identification of current problems is of value for identifying short-term actions that may be taken to alleviate problems that justify an interim solution. This may involve such things as demand management or minor geometric improvements that can provide a "quick fix" at a reasonable cost.

Long-term strategies designed to solve anticipated problems should be chosen in the context of the broader system in which the corridor operates. Thus, there should be an interaction with the larger perspective of the regional and subarea planning process. When this is not done, as often happens, the strategies employed may result in shifts in travel patterns that have a negative impact for other actions taking place in the subarea or region.

DEFINITION OF A PROBLEM

A corridor can be defined as including a freeway facility, crossing and parallel arterials, and in some cases, other facilities such as transit. It may also include bicycle and pedestrian paths on separate rights-of-way. The nature of the problems present in a corridor may be classified as:

- Mobility.
- Safety.
- Environmental.

As indicated in task 1 of figure 2, the process usually starts, and the corridor is chosen for study, based on a perceived problem. The most frequently occurring problem that triggers corridor study is congestion. However, it is possible that safety may also be a primary initiating factor. Whileenvironmental concerns may occasionally be initiating factors, they are more commonly part of the issues addressed in the course of making an improvement.

The corridor problems perceived at the outset of this process are usually defined in highly qualitative and general terms. Statements such as "congestion between 15th and 23rd Avenues," "queues every morning in the central section," or "serious accidents frequently occurring at the north interchange,' are typical of the problem definition at this early stage. It remains for the analyst to verify, further refine, and define the problem(s) in the corridor.

How then does one decide if a perceived problem is a real problem? Furthermore, how does one adequately describe the problem so that a decision-making process may be formulated to progress toward its elimination?

The fact that a problem exists indicates that there is an objective or level of expectancy that is not being met. However, the perception that a problem exists is relative. What may be considered to be a problem in a small urban area with less traffic is often not considered a problem in a major metropolitan area. The objective or level of expectancy is likely to be different in each area. But once the objective is defined, a failure to meet it could be defined as a problem. An objective can sometimes change over time, in which case a situation may fall into or out of problem status even though there may have been no change in the characteristics of the traffic itself.

The most commonly used method to quantify a congestion problem and convey its meaning to the public is the level of traffic service. Levels A through F have become well-established parts of the vocabulary in council meetings and citizen groups throughout the country. Most cities and State agencies have established as standards a set of levels of service that they believe are appropriate to maintain. A freeway operating at level of service E would be sald to need further improvement if the defined standard was D.

Problems could also be defined in other ways, such as the duration of congestion (queuing), an accident rate that is significantly higher than the rate for similar sections, or speed deterioration below a given threshold. When a level of service threshold is set, other numerical thresholds are also being established (such as a density threshold for freeway mainline sections). Engineering analysis will generally deal directly with the numerical measures, but this will often need to be translated to level of service when conversing with the public since the public is more familiar with that terminology. Visual descriptions of level of service are a help in developing a more consistent interpretation of level of service. In an engineering evaluation, the problem is normally defined in quantitative terms such as minimum speed, average speed, maximum length of queue, or duration of congestion.

Congestion problems can also be classified as recurring or non-recurring. Recurring congestion normally refers to problems that occur during peak commuting periods on weekdays. in some areas, weekend recreational traffic is also a source of recurring congestion. While the improvement strategies for recurring congestion are normally considered to be geometric in nature, they can also include operational measures such as

ramp metering. Possible sources of non-recurring congestion are freeway incidents and special events.

While the elimination of incidents is desirable, it must be accepted that incidents will occur, and strategies must be devised to minimize their effects. A problem associated with non-recurring congestion could be defined as a level of incident congestion that has become intolerable. This is usually a qualitative assessment, rather than a specific measure of the magnitude of congestion. There is a role for simulation models in addressing both recurring and non-recurring congestion problems.

PROBLEMS VS. CAUSES

Problems in a corridor have been defined as unmet corridor objectives. Problems should be differentiated from causes, i.e., those things that may be the underlying reason for the non-attainment of the objective. For example, the problem may be that the level of service is below the established standard. In many cases the cause may be obvious. In other cases, failure to think through possible causes may result in ovenooking an easier or less expensive solution. For example, poor signal timing on a parallel arterial or service road may result in significant numbers of short trips using the freeway and the creation of additional weaving volumes that unnecessarily break down mainline traffic flow. The less obvious solution could be very simple, whereas the more obvious solution (adding a lane to the freeway) could be very expensive. While this may comprise only a short-term solution, it may represent the best investment of available public funds. There will frequently be multiple causes to a problem, some of which suggest modifications to the geometry, while others suggest modifications to operational strategies or to traffic demand.

One way to trace a congestion problem back to a possible cause is to establish the location of bottlenecks. A bottleneck can usually be identified in the vicinity of the transition between a low speed section followed by a section with high speeds. The most visible bottlenecks are where a traffic queue begins. Existing bottlenecks can usually be identified by observing the location of queues in the field. Potential future bottlenecks can be identified through simulation.

Sometimes bottlenecks can be masked by other bottlenecks, either through queues that back up from a downstream bottleneck through an upstream bottleneck, or through an upstream bottleneck that does not allow a downstream bottleneck condition to materialize. The latter would only be apparent if the upstream bottleneck were improved. This is where freeway simulation models can play a significant role. The consequences of eliminating bottlenecks can be predicted prior to committing to a decision, resulting in a more comprehensive analysis of the problem and designing of solutions.

The illustration in figure 12 is a case in point. The first contour diagram shows an existing bottleneck condition. The simulation of the same section with a capacity increase in the bottleneck area indicates that a different, previously unknown bottleneck is looming downstream. However, it was not visible as a bottleneck previously because of the restraint of traffic upstream.   If this downstream bottleneck had a capacity just slightly higher than that of the upstream bottleneck, little would be accomplished by improving the upstream bottleneck, While this fact could possibly be deduced from observation by an experienced

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TIME            DIRECTION OF TRAVEL ··················>                    BEGIN
SLICE ...........................................................................  TIME

16 .                                                                      . - 17:45
15 .                                 ···                                  . - 17:30
14 .                             ··········                               . - 17:15
13 .                      ···························                      . - 17:00
12 .                  ································        NO APPARENT   . - 16:45
11 .                      ·······················          DOWNSTREAM     . - 16:30
10 .                         ····················          BOTTLENECK     . - 16:15
 9 .                            ················                          . - 16:00
 8 .                             ·········                                . - 15:45
 7 .                              ····                                     . - 15:30
 6 .                                                                       . - 15:15
 5 .                             UPSTREAM                                  . - 15:00
 4 .                             BOTTLENECK                                . - 14:45
 3 .                                                                       . - 14:30
 2 .                                                                       . - 14:15
 1 .                                                                       . - 14:00

 .................................................................................
    :   :  ::            :  :       :           :        :   : :    . :: :
    01  02 03  05        06 07      08          09       10  11 12  13  15 16
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Existing Conditions


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TIME            DIRECTION OF TRAVEL ··················>                    BEGIN
SLICE ...........................................................................  TIME

16 .                                                                      . - 17:45
15 .                                                                      . - 17:30
14 .                                                 ······               . - 17:15
13 .                                ····          ················        . - 17:00
12 .                                ······        ·················       . - 16:45
11 .                                ·····         ················        . - 16:30
10 .                                ···           ·······                 . - 16:15
 9 .                                              ···                      . - 16:00
 8 .                             UPSTREAM                                  . - 15:45
 7 .                             BOTTLENECK       DOWNSTREAM               . - 15:30
 6 .                             PARTIALLY        BOTTLENECK               . - 15:15
 5 .                             ALLEVIATED       BECOMES                  . - 15:00
 4 .                                              APPARENT                 . - 14:45
 3 .                                                                       . - 14:30
 2 .                                                                       . - 14:15
 1 .                                                                       . - 14:00

 .................................................................................
    :   :  ::            :  :       :           :        :   : :    . :: :
    01  02 03  05        06 07      08          09       10  11 12  13  15 16
```

Upstream Bottleneck Improved

ASTERISK DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION.

Figure 12. Improvement of an upstreeam bottleneck reveals a downstream bottleneck.

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engineer and from some basic capacity calculations, the level of benefit of lack thereof could readily be quantified with a simulation model. Had the analysis not been done with simulation, the expected benefit would have been computed without taking into account the additional downstream delay. The ability to analyze interactions between sections and to thereby conduct a better analysis of the problem/cause relationship is clearly a significant reason to consider the use of a simulation model.

Figure 13 shows the opposite problem. A major downstream bottleneck grows to engulf an upstream bottleneck in a queue prior to the formation of a queue at the upstream bottleneck. When the downstream bottleneck is improved, the existence of the upstream bottleneck becomes apparent.

One of the important lessons concerning the interaction between bottlenecks is that two or more closely spaced bottlenecks with similar volume/capacity ratios cannot be evaluated independently. The improvement of only one will usually only succeed in increasing the prominence of the other without significantly reducing delay. The freeway must be seen as a system, not just as a series of independent segments. Thus, even the "Freeway Systems" chapter of the *Highway Capacity Manual* (HCM) is quite inadequate to take these interactions into consideration, as the HCM has no method of analytically accounting for these interactions. Simulation is essential for a complete analysis.

A characteristic of a well-balanced freeway is the absence of dramatic differences in speed throughout its length. This is frequently diicult to achieve though because lane capacity is incremented in approximate 2,000 vehicles/h increments (one lane of capacity), whereas demand does not constrain itself to changing in the same increments. It typically changes in smaller increments at on-ramps and off-ramps (although on-ramp and off-ramp volumes can be greater than 2,000 at system interchanges and other major interchanges). In terms of time, volume changes in a continuum, both in terms of hourly demand and in growth over time. Demand may also be so massive at a particular point that no geometric or operational strategy could effectively deal with it.

Table 4 lists possible causes associated with mobility problems on freeways. These have been dassified according to the physical elements of the freeway. They are:

1. Interchanges.
2. Freeway Mainline.
3. Highway System.
4. Traffic incidents.

These are further subdivided for ease of reference.

Appendix A provides an extensive discussion of the causes associated with mobility problems on freeways. It provides an indication of what symptoms should be looked for in tracing down an underlying cause. By property assimilating and interpreting this information, an engineer will be able to more accurately identify the solution that will directly address the cause. it is not easy to teach this skill. Much of it comes from experience and an inherent ability to fit the pieces of a complex puzzle together. But the material in appendix A should at least introduce additional ideas that the engineer can take into account in addressing these problems.

Table 4. Possible causes associated with mobility problems on freeways.

1. **INTERCHANGES**

1.1 **Ramp Merge**

    1.1.1.   Inadequate Speed Change Lane Length
    1 .1.2.   Inappropriate Design Features (alignment at merge, merging end configuration, cross section, etc.)
    1 .1.3.   Demand Too large
    1 .1.4.   Left-Hand Ramp

1.2 **Ramp Diverge**

    1.2.1.   Inadequate Speed Change Lane Length
    1.2.2.   Inappropriate Design Features (alignment at diverge, diverging end configuration, cross section, etc.)
    12.3.   Demand Too Large
    12.4.   Left-Hand Ramp at Diverge

1.3 **Ramp Proper**

    1.3.1.   Horizontal Alignment Too Limiting (sharp curves, limited sight distance, etc.)
    1.32.   Vertical Alignment Too Limiting (steep grades, short curves, limited sight distance)
    1.3.3.   Cross Section Too Limiting (narrow lanes and shoulders, inadequate super-elevation, roadside hazards, etc.)
    1.3.4.   Demand Too Large (insufficient capacity)

1.4 **General Interchange**

    1.4.1.   Basic Configuration Not Appropriate
    1.4.2.   Route Continuity Violated
    1.4.3.   Slippery Pavement Surface
    1.4.4.   Poor Pavement Condition
    1.4.5.   Lack of Traffic Enforcement

2. **FREEWAY MAINLINE**

2.1 **Vertical Element**

    2.1.1.   Steep Grade
    2.1.2.   Inadequate Vertical Curve

Table 4. Possible causes associated with mobility problems on freeways (Continued).

2.2　**Horizontal Element**

    2.2.1.　Lanes
        2.21.1.　　　Insufficient Number (basis and/or auxiliary)
        2.2.1.2.　　　Dropped or Added
        2.2.1.3.　　　Continuity (not maintained)
        2.2.1.4　　　Balance Violated

    2.2.2.　　　Curvature Too Sharp and/or Super-Elevation Inadequate
    2.2.3.　　　Weaving Section Too Short

2.3　**Cross Section Elements**

    2.3.1.　　　Structural Elements Negatively Affect Driver Behavior
    2.3.2.　　　inadequate Lane Width

3.　**HIGHWAY SYSTEM**

3.1　**Missing Links**

3.2　**Lack of Parallel Capacity**

3.3　**Overlap of Routes**

4.　**TRAFFIC INCIDENTS**

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TIME                    DIRECTION OF TRAVEL  ----------------->                    BEGIN
SLICE  ....................................................................................  TIME

   .                                                                                          .
 16 .                                                                        .             . - 17:45
 15 .                                         --             ********       . - 17:30
 14 .                                      *********************           . - 17:15
 13 .                               **************************************  . - 17:00
 12 .                            ******************************************  . - 16:45
 11 .                         ********************************************   . - 16:30
 10 .                        *********************************************   . - 16:15
  9 .                         ********************************************   . - 16:00
  8 .                           ******************************************   . - 15:45
  7 .                            ****************************************    . - 15:30
  6 .                               *********************************        . - 15:15
  5 .                  UPSTREAM                          ****                . - 15:00
  4 .                  BOTTLENECK                                            . - 14:45
  3 .                  NOT                          MAJOR                    . - 14:30
  2 .                  APPARENT                     DOWNSTREAM               . - 14:15
  1 .                                               BOTTLENECK               . - 14:00
   .                                                                                          .

     ........................................................................................
      :       :  :   ::           :   :          :              :         :   :  :    :  :  :
     01     02 03   05          06 07          08            09        10  11 12   13  15 16
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Existing Condition

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TIME                    DIRECTION OF TRAVEL  ----------------->                    BEGIN
SLICE  ....................................................................................  TIME

   .                                                                                          .
 16 .                                                                        .             . - 17:45
 15 .                                                                        . - 17:30
 14 .                                                       ******           . - 17:15
 13 .                            ****             **************             . - 17:00
 12 .                            ******           ******************         . - 16:45
 11 .                            *****            **************             . - 16:30
 10 .                            ***              *******                    . - 16:15
  9 .                                             ***                        . - 16:00
  8 .                  UPSTREAM                                              . - 15:45
  7 .                  BOTTLENECK                DOWNSTREAM                  . - 15:30
  6 .                  BECOMES                   BOTTLENECK         .        . - 15:15
  5 .                  APPARENT                  PARTIALLY                   . - 15:00
  4 .                                            ALLEVIATED                  . - 14:45
  3 .                                                                        . - 14:30
  2 .                                                                        . - 14:15
  1 .                                                                        . - 14:00
   .                                                                                          .

     ........................................................................................
      :       :  :   ::           :   :          .              :         :   :  :    :  :  :
     01     02 03   05          06 07          08            09        10  11 12   13  15 16
```

Upstream Bottleneck Improved

ASTERISK DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION.

Figure 13. Improvement of a downstream bottleneck reveals an upstream bottleneck.

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A discussion of traffic incidents cannot be readily fii into the same framework as the discussion for the Other item; yet incident management is an extremely important aspect of freeway operations. Incident management strategies can also be evaluated using simulation models. In fact, it is not possible to evaluate the impact of incidents using the Highway Capacity Manual, since a delay-producing incident condition inherently involves a queuing situation. Other methods less sophisticated than simulation have been developed to evaluate the delays caused by incident conditions. One of the methods, based on the Federal Highway Administration (FHWA) report entitled Alternative *Surveillance Concepts and Methods of Freeway Management* has been programmed into a spreadsheet. It evaluates the incident within the context of a single section of freeway, with a mainline entry volume. It does not incorporate the effects of intermediate ramps and is limited in the number of demand changes it can accommodate. Although this simplified method may provide a ballpark estimate of delay, it cannot provide the more detailed and accurate estimate afforded by simulating the freeway with all its entry and exit points and its changes in demand over time.

CANDIDATE STRATEGIES FOR SOLVING IDENTIFIED PROBLEMS

Knowing the type and nature of the problem is not sufficient for identifying the appropriate strategies that might be introduced. One must have information about causes to make intelligent selections among possible means for improvement, and to narrow the choices to a workable set.

It is difficult to develop a cookbook methodology for selecting a specific strategy to address every possible problem and cause, nor would it be appropriate to do so. There are many variables that come into play in making such a decision, and the ability of engineers and decision-makers to assess each unique situation and to take these factors into account is indispensable. However, it is easy for these individuals to overlook the investigation of certain aspects of the problem. To guard against this, a checklist approach is appropriate to help trigger potential solutions that may have greater effectiveness or reduced cost. This section presents such a checklist. It is intended for use by engineers faced with designing solutions that most effectively address the problems at hand. Each solution is associated with a possible cause.

Table 5 provides an extensive checklist for identifying potential improvement strategies. Arrayed against each possible cause of a mobility problem are possible associated safety and environmental problems and potential strategies for relieving or eliminating the problem. There are numerous references that speak to the details of these strategies, identifying more' specific design considerations, potential benefits, and possible negative impacts. It is not the intent of this document to cover all of these aspects in detail. Rather, table 5 contains reference numbers keyed to the reference list following the table. The reader is encouraged to consult these references for further information.

Table 5 and the associated references will assist the analyst and decision-maker in choosing the major improvement categories. It is the purpose of simulation and other analyses to fine-tune the selection to fit the need of each unique situation. This takes place through an interactive analysis and evaluation process as described in chapter 6. The material in chapter 5 is a key input to that process.

Table 5. Checklist of possible causes and strategies associated with mobility problems of freeways.

Possible Causes	Possible Associated Safety and Environmental Problems	Candidate Strategies	Reference Numbers
1. INTERCHANGES			
1.1 Ramp Merge			
1.1.1 - Inadequate Speed Change Lane Length	- Sideswipe, angle and rear-end accidents on ramp or mainline	- Lengthen speed change lane - Use shoulder for extending speed change lane	1,2
1.1.2 - Inappropriate Design Features alignment at merge, merging end configuration, cross section, etc.)	- Sideswipe and angle Incidents - Early entry at high speed differential - Rear-end accidents on ramp or mainline - Excessive and erratic lane changing - Severe braking - High accelerated noise	- Reduce angle of merge - Reduce curvature at merging end - Provide designs that meet or exceed minimums - Eliminate sight restrictions	1,2
1.1.3 - Demand Too Large	- Rear-end accidents - Severe braking - High acceleration noise - High pollutant levels	- Add mainline capacity - Add merge capacity - Add ramp-proper capacity - Control ramp volume	1,3,24
1.1.4 - Left-Hand Ramp	- High speed differential at merge - Sudden lane-changes on mainline near merge - Sideswipe and angle accidents - Rear-end accidents between mainline and entering vehicles	- Eliminate ramp - Replace with right-hand ramp - Control ramp volume - Carry ramp lane on as auxiliary lane mainline vehicles	2,24

Table 5. Checklist of possible causes and strategies associated with mobility problems of freeways (Continued).

Possible Causes	Possible Associated Safety and Environmental Problems	Candidate Strategies	Reference Numbers
1.2 Ramp Diverge 1.2.1 - Inadequate Speed Change Lane Length	- Rear-end accidents on freeway - Slowing of exiting vehicles on mainline - High frequency on lane changes by mainline vehicles near diverge	- Lengthen speed change lane - Use shoulder to lengthen speed change lane - Create auxiliary lane that is carried off at exit	1,2
1.2.2 - Inappropriate Design Features (alignment at diverge, diverging end configuration, cross section, etc.)	- Rear-end accidents on freeway - Slowing of exiting vehicles on mainline - High frequency of lane changes by mainline vehicles near diverge	- Change angle of diverge - Reduce curvature at diverging end - Provide designs that meet or exceed minimums - Eliminate sight restrictions	1,2
1.2.3 - Demand Too Large	- Rear-end accidents - Severe braking - High acceleration noise - High pollutant levels	- Add mainline capacity - Add diverge capacity - Add ramp-proper capacity - Control ramp volume	1,3,24
1.2.4 - Left-Hand Ramp at Diverge	- High speed differential - Sudden lane-changes on mainline near merge - Rear-end accidents between mainline and entering vehicles - Sideswipe and angle accidents involving mainline vehicles	- Eliminate ramp - Replace with right-hand ramp - Close ramp for critical periods	2

**Table 5. Checklist of possible causes and strategies
associated with mobility problems of freeways (Continued).**

Possible Causes	Possible Associated Safety and Environmental Problems	Candidate Strategies	Reference Numbers
1.3 Ramp Proper 1.3.1 - Horizontal Alignment Too Limiting (sharp curves, limited sight distance, etc.)	- Excessive braking - High acceleration noise - Rear-end accidents	- Modify geometry - Increase set-backs to sight-line inhibitors - Improve warning signs	1,3,4,5
1.3.2 - Vertical Alignment Too Limiting (steep grades, short curves, limited sight distance)	- Rear-end accidents - Sideswipe accidents	- Modify geometry - Provide climbing lane	1,3,4,5
1.3.3 - Cross Section Too Limiting (narrow lane and shoulders, inadequate super-elevation, roadside hazards, etc.)		- Modify geometry - Remove hazards or protect	1,3,4,5
1.3.4 - Demand Too Large		- Increase number lanes - Control volume - Modify capacity at cross street	1,3,4,24
1.4 General Interchange 1.4.1 - Basic Configuration Not Appropriate	- High frequency of erratic maneuvers - High volume of mainline weaving - High frequency of lane changing	- Modify configuration - Control ramp volumes - Grade separate conflicting movements at adjacent interchanges - Close selected ramps - Use collector-distributor or roadways to segregate flows	1,2,6,7

Table 5. Checklist of possible causes and strategies associated with mobility problems of freeways (Continued).

Possible Causes	Possible Associated Safety and Environmental Problems	Candidate Strategies	Reference Numbers
1.4.2 - Route Continuity Violated	- High frequency of erratic maneuvers	- Modify interchange - Modify route designations - Modify network	1,7
1.4.3 - Slippery Pavement Surface	- High proportion of single vehicle run-off-road accidents - Low skid number - Excessive skidding under wet conditions	- Pavement surface treatment	8,9
1.4.4 - Poor Pavement Condition	- Excessive braking - High frequency of lane changing - High frequency of rear-end and side-swipe accidents	- Repairs and resurfacing - Replacement - Control weight and volume of heavy vehicles	8,10
1.4.5 - Lack of Traffic Enforcement	- High frequency of violations	- Increase enforcement - Improve targeting of enforcement - Improve public information and education programs - Apply new technologies - Provide enforcement refuge	11
1.4.6 - Inadequate Lighting	- High relative frequency of nighttime accidents	- Improve lighting (continuous, interchanges, other critical locations)	5,8,12

**Table 5. Checklist of possible causes and strategies
associated with mobility problems of freeways (Continued).**

Possible Causes	Possible Associated Safety and Environmental Problems	Candidate Strategies	Reference Numbers
1.4.7 - Incompatible Vehicle Mix	- High relative frequency of accidents between different classes of vehicles	- Separate vehicles - Modify design - Control attributes of vehicle mix	13,14,15,16,17
2. FREEWAY MAINLINE **2.1 Vertical Element**			
2.1.1 - Steep Grade	- Slow moving vehicles - Excessive braking - High frequency of rear-end accidents	- Reduce grade - Add climbing - Control volume of heavy vehicles	1,3
2.1.2 - Inadequate Vertical Curve	- Sudden slow/braking - Rear-end accidents	- Flatten curve	1,3
2.2 **Horizontal Element** 2.2.1 - Lanes 2.2.1.1 Insufficient Number (basic and/or auxiliary)	- High frequency of rear-end accidents	- Increase number lanes - Convert shoulder to a lane - Reduce lane width - Create reversible/ contra-flow lanes - Develop parallel capacity - Control volume	3,18,19,24
2.2.1.2 Dropped or Added	- High frequency of run-off-road and sideswipe accidents - High frequency of erratic maneuvers - High frequency of sideswipe accidents	- Relocate drop/addition - Eliminate by extending dropped/added lane to next exit/entrance	1,2,7,20

**Table 5. Checklist of possible causes and strategies
associated with mobility problems of freeways (Continued).**

Possible Causes	Possible Associated Safety and Environmental Problems	Candidate Strategies	Reference Numbers
2.2.1.3 Continuity (not Maintained)	- Excessive frequency of	- Reconfigure interchanges to allow continuity	1,2,7
2.2.1.4 Balanced Violated	- Excessive frequency of lane changes - High frequency of erratic maneuvers - Excessive frequency of rear-end and sideswipe accidents	- Modify lane configurations to achieve balance - Reconfigure interchanges to achieve balance	1,7,21,22
2.2.2 - Curvature Too Sharp and/or Super-Elevation Inadequate	- Relatively high frequency of single-vehicle run-off-road accidents - Excessive frequency of lane encroachment	- Flatten curve - Improve super-elevation - Improve skid number - Provide transition - Provide lighting - Increase offsets to increase sight distance	

Possible Causes	Possible Associated Safety and Environmental Problems	Candidate Strategies	Reference Numbers
2.2.3 - Weaving Section Too Short	- Excessive frequency of erratic maneuvers - Excessive braking and high acceleration noise - Relatively high frequency of rear-end and sideswipe accidents	- Increase length of section - Create collector-distributor road to segregate weaving form mainline - Modify configuration of interchanges to eliminate weaving - Close selected ramps (permanently or during critical periods) to eliminate weaving - Control weaving volumes (e.g., through striping)	
2.3 Cross Section Element 2.3.1 - Structural Elements Negatively Affect Driver Behavior	- High frequency of erratic maneuvers - Excessive braking - Excessive lane encroachments - Relatively high frequency of rear-end and sideswipe accidents	- Remove/relocate elements - Add attenuation devices - Add screening devices - Increase offset to device	
3. HIGHWAY SYSTEM 3.1 – Missing Links		- Provide missing link - Provide parallel capacity	

Table 5. Checklist of possible causes and strategies associated with mobility problems of freeways (Continued).

Possible Causes	Possible Associated Safety and Environmental Problems	Candidate Strategies	Reference Numbers
3.2 – Lack of Parallel Capacity		- Provide parallel capacity	
3.3 – Overlap of Routes		- Modify network - Develop dual roadway system in corridor	1,7
4. TRAFFIC INCIDENTS 4.1 - Incident Detection/ Verification		- Closed-circuit TV - Loop detection - Aerial observers - Incident reporting number for cellular phone	
4.2 - Incident Response and Clearance		– Freeway service patrols – Accident investigation sites – Emergency access points – Additional specialty equipment – Response preplanning	
4.2 – On-Scene Management		– Communications equipment and protocols – Mutual aid agreements – Emergency detour signing	
4.3 - Motorist Information		– Variable message signs – Highway advisory radio – Coordination with the media – Pre-trip information	

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Traffic incidents can be clearly identified as a major cause of freeway mobility problems. Incident management involves minimizing the effect of those incidents once they occur. Their impact on traffic can be minimized by:

- Reducing the time for incident detection and verification.
- Reducing incident response and clearance time.
- Exercising proper on-scene management of personnel and traffic (this may include route diversion).
- Providing timely, accurate information to the public.

A list of possible strategies for dealing with these areas is provided in table 5.

CHAPTER 6. APPLICATION OF SIMULATION MODELS IN FREEWAY DESIGN AND OPERATIONS

Chapter 2 provided an overview of the process of planning and operational analysis for a freeway corridor. it indicated that two of the primary uses of freeway simulation models are in refining freeway design decisions and in evaluating operational improvements that cannot be evaluated through other means. This chapter presents more specific procedures and guidelines for applying freeway simulation models.

CORRIDOR ANALYSIS TASK STRUCTURE

The discussion in this chapter is organized around a series of tasks, much as a scope of work would be written for conducting a specific project. The tasks follow the format previously indicated in figure 2, repeated here as figure 13 because of its importance to this discussion.

Figure 2 indicates the tasks associated with three basic phases in corridor analysis using simulation models: Phase 1 - Study Preparation and Model Calibration Phase 2 - Short-Term Analysis, and Phase 3 - Long-Term Analysis. Any given study may include only a short-term analysis or only a long-term analysis. if both are conducted, they will still be relatively independent, except that the strategies examined for the long-term analysis may be dependent on the adequacy of the short-term solutions. The short-term analysis may also be a form of phasing analysis that is actually conducted after the long-term analysis is completed to assist in defining intermediate stages of improvement.

The task-by-task discussion assumes that the reader has a basic understanding of the concepts and operation of freeway simulation models. It does not attempt to repeat information provided in any of the user manuals for the models, nor does it present an extensive treatment of the traffic flow theory upon which the models are built. Rather, it explains the process of using the simulation models for corridor analysis in the same way that an engineer experienced in simulation would explain the process to someone conducting such an analysis from scratch. It presents the basic information for conducting the task activities as well as contingency plans to address the less-than-perfect conditions that frequently occur in the course of analysis. It provides sample formats for spreadsheets and figures that can be used in preparing and analyzing data. Each task is discussed in the following format:

- Task Name.
- Task objective.
- Task Input.
- Task Activities.
- Task Products.

TYPICAL CORRIDOR ANALYSIS SCHEDULE

Figure 14 presents a typical schedule for a corridor study involving freeway simulation. Depending on the nature of the study, the tasks for analyzing the short-term strategies would not be performed if only a long-term analysis is conducted. Likewise, the long-term tasks would not be performed if only a short-term analysis is conducted. Many of the tasks are relatively short in terms of time, but yet are important in maintaining the needed direction for the study.

A typical length of time for the evaluation would be 1 yr. However, the analysis for some projects could be conducted in 4 months, if needed. if a validated simulation model already existed for the corridor, the analysis could be conducted in even a shorter timeframe. The study could also last much longer, as may be the case when a major environmental evaluation is involved. The analysis tool employed will also have a bearing on the length of time necessary. Generally speaking, the microscopic simulation models require more time than the macroscopic models. The primary difference is in the model validation stage, but there could be other time implications as well, depending on the strategies being evaluated. As the tools are improved, there should be less difference in the time requirements among models, and the decision to use a particular model will be based more on its ability to replicate traffic conditions and to evaluate specific operational features. The schedule will be referred to at various points in the discussion that follows.

The first task in figure 2 assumes that an individual or group has posed the question "Should a study of the freeway corridor be undertaken?" Task 1 is designed to answer that question. The study would most often take the form of a project development effort, which may or may not include an environmental evaluation. Another wmmon theme would be a feasibility analysis and conceptual design for operational improvements.

Assuming the decision is made to pursue the study, the remaining tasks would follow in sequence. The schedule defines the timeframe for task 1 as "variable." The process of identifying the proper course of action, lead agency, scope of work and other items could, in actuality, take an extended period of time. The level of effort involved in the study will vary, depending on the magnitude of the study area, the issues involved, and the simulation techniques employed.

There are several significant milestones shown in figure 2, most of which are oriented around major products. These include:

- Modal validation report.
- Existing conditions and problems report.
- Evaluation of Short-Term Solutions report
- Evaluation of Long-Term Solutions report.
- Final study report

Each task is begun on a new page, beginning on the page that follows.

TASK	MONTH											
	1	2	3	4	5	6	7	8	9	10	11	12
PHASE I												
1 Identify need for study	(variable - assumed to have taken place before project begins)											
2 Define corridor objectives												
3 Define measures of effectiveness												
4 Define horizon, study area, time per												
5 Select analysis tools												
6 Establish operational standards												
7 Identify geometric standards												
8 Collect traffic data												
9 Document existing conditions												
10 Create & verify model setups												
11 Calibrate & validate models												
Model Calibration & Validation Report					•							
12 Identify problems & possible causes												
Existing Conditions and Problems Report												
PHASE II												
13 Identify short-term strategies												
14 Simulate short-term strategies												
15 Evaluate results												
16 Refine strategies												
17 Make short-term recommendations												
18 Document results												
Evaluation of Short-Term Solutions Report								•				
PHASE III												
19 Define future regional condition												
20 Obtain traffic forecasts					(variable)							
21 Simulate future no build condition												
22 Identify future problems												
23 Identify long-term strategies												
24 Obtain modified forecasts				(may require longer depending on project)								
25 Simulate long term strategies												
26 Evaluate results												
27 Refine strategies												
28 Make long-term recommendations												
29 Document results												
Evaluation of Long-Term Solutions Report												•
Final Report												•

* = Report to be produced

Figure 14. Typical schedule for conducting project involving simulation analysis.

PHASE I: STUDY PREPARATION AND MODEL CALIBRATION

Task 1: Identify Need for Study

Task Objective: Make an Initial determination of whether a formal study of freeway deslgn or operatlons needs to be conducted.

Task Input:

- Basic understanding of the corridor and its operation.

- Information from prior studies or from observation.

- Comments from the public suggesting that the freeway corridor has a problem (or will have a problem) to be solved.

Task Activities:

A freeway corridor study is normally initiated from the recognition of staff or agency decision-makers that the current operation (or expected future operation) is unacceptable. This is often a perception with little or no supporting data except what is maintained in the ongoing monitoring of the corridor or from the observation of the individuals involved. The decision to conduct the study may be initiated by a single lead agency, but may also involve the decision of a multi-jurisdictional group, such as a metropolitan planning organization. A department of transportation would often be considered as the lead agency, as most of the freeways are State roadways. Typical task activities would include:

- Establishment of an appropriate intra-agency or multi-agency Corridor Study Steering Committee, to be active throughout the course of the study.

- Definition of study objectives.

- Development of a scope of work

- Assignment of agency responsibilities, both technical and funding.

Task Products:

- Memoranda of understanding, where needed, identifying agency responsibilities.
- Designation of lead agency and/or individual as project manager.
- Study objectives and scope of work.

- Determination of whether to seek outside services.
- Funding plan for the study.

Task 2: Define Corridor Objectives

Task Objective: Identify primary objectives that will guide the development and evaluation of corridor alternatives.

Task Input:

- Regional and local objectives and policies.
- Prior studies in the corridor, if any.
- Concerns of elected officials

Task Actlvlties:

The planning and operation of an individual corridor exists within the framework of urban area objectives and policies. The study cannot be conducted independently from the future visions of the area already established. At the same time, there may be directions that seem to be particularly appropriate for the specific corridor under study. For example, it may be determined by the steering committee that the development of the coridor as a transit corridor, without significant highway improvements, is the direction that should be pursued. In this case, it is unlikely that freeway simulation would play a significant role in the analysis. The task descriptions discussed hereafter assume that the objectives for the corridor will present a direction that can be analyzed using the simulation models.

Sample statements of corridor objectives include:

- Reduce travel time for all vehicles.
- Reduce peak period delay from traffic incidents.
- Create incentives for high occupancy vehicles.
- Improve safety.

Although these tend to be generalized statements, they are the foundation upon which the remainder of the study is built. To study something that is clearly counter to an objective of the region or subregion will likely result In wasted effort

While the establishment of the objectives may not preclude the pursuit of strategies that do not directly address those objectives, providing this direction at the outset of the project will help to define expectations for the study and avoid misunderstandings later on. The definition of corridor objectives should not be viewed as an opportunity to pre-establish the recommended action. However, it is important to determine such things as whether demand-reduction strategies are to be evaluated or whether incident management strategies are to be

within the scope of the evaluation. Often, the determination of corridor objectives would be undertaken hand-in-hand with the development of the scope of work and prior to the involvement of the analysts.

Task Products:

- "Corridor Objectives and Measures of Effectiveness" memorandum (combined result of tasks 2 and 3), distributed to steering committee members.

Task 3: Define Measures of Effectiveness

Task Objective: Define the variables that will be used to measure changes in traffic performance and that can be used to determine If corridor operational standards are achieved.

Task Input:

- Corridor objectives.
- Expected availability of data.

Task Activities:

The measures of effectiveness (MOE's) flow directly from the corridor objectives. However, they must also consider the ability of the analysis tools to generate those measures. Therefore, it is an interactive process and sometimes a compromise between the ideal and the possible or affordable. If the entire set of MOE's cannot afford to be measured, those MOE's most critical to evaluating improvements should be identified to ensure that these MOE's are specifically measured.

Table 6 shows a sample set of corridor objectives related to MOE's. It also shows the source from which the MOE's are to be generated.

Task Output:

- "Corridor Objectives and Measures of Effectiveness' memorandum.

Table 6. Sample objectives, MOEs, and data sources.

Objectives ·	MOE's	Sources
1. Increase vehicle capacity during peak periods.	Peak hour vehicle volume	HCM capacity calculations. Peak hour volume from simulation at selected locations.
2. Increase person-carrying capacity.	Peak hour person volume	Peak hour and peak period person volume at selected locations.
3. Decrease travel time.	Average speed Point-to-point travel time Speed contour Queue contour	Weighted ave. speed from HCM. VMT+VHT from simulation. Computed travel time between points (HOV and non-HOV). Simulation model output. Simulation model output.
4. Minimize emissions impact.	Tons of CO/day Tons of HC/day Tons of NO_x/day	Emissions inventory model (could be obtained from simulation model if demand remains constant).

Task 4: Define Horizon Year, Study Area, and Analysis Time Periods

Task Objective: Define basic parameters governing: how far Into the future improvements are to be planned, the section of corridor over which they are to be planned, and the peak periods that will govern the design.

<u>**Task Input**</u>:

- Corridor objectives.
- Basic purposes for the study.

<u>**Task Activities**</u>:

Although the decisions governing horizon year, study area (e.g., corridor length and width), and peak period/directions to be analyzed, are not difficult to make, they have profound impact on the course the study will take. Some of the issues involved in making each decision were discussed in the broader context of chapter 2, but are repeated below for the benefit of the model user.

Horizon year:

- A basic question for the study is whether it should examine short-term improvements, long-term improvements, or both. If design for long-term improvements is the emphasis of the study, the horizon year would normally coincide with the year currently used in the region for long-term planning. Using the same year or Set Of years is important, as the study will need to draw from either existing forecasts or forecasts modified from the regional planning model.

- Traffic operational improvements will normally be evaluated in a short-term setting. Geometric improvements will normally be evaluated in a long-term setting. However, certain geometric improvements, such as the addition of an auxiliary lane, or even the construction of an additional median-side lane (without structure work or ramp geometry changes) may be appropriate for short-term analysis.

- If only short-term improvements are to be analyzed, the horizon year could be established as 1 to 5 years from the existing condition, anticipating reliance on growth factors for any short-term traffic forecast.

study area:

- The study area is also defined on the basis of the types of improvements to be evaluated;' Long-term improvements, which tend to affect a larger geographic area, usually require a larger study area than short-term improvements, depending on the exact nature of those improvements.

- Typical corridor lengths - For a major corridor study, it is not unusual to have a corridor of 15 mi (24 km) or longer. Both FREFLO and FRESIM currently have limitations in the length of freeway to be studied. FREFLO would normally be limited to 15 mi (24 km) if 15-min time slices were being used. FRESIM currently operates under a constraint of vehicle storage, which typically limits section length to 5 ml (8 km) for four-lane sections and 10 mi (16 km) for two-lane sections. However, keep in mind that the limitation should be based on the future cross section of the facility, not merely the existing cross section. As computing power increases, it is expected that the vehicle storage limitation of FRESIM will be relaxed, and longer sections can be simulated. if a longer section than indicated above must be simulated, two or more separate simulations could be constructed end-to-end, provided mat the terminal points of the sections do not encounter congestion. In some cases the evaluation may focus on a specific trouble spot, such as a weaving section. This could result in a section length of as little as one-half mi (0.8 km). FRESIM is particularly appropriate for the analysis of such a section. However, If queues extend upstream of the weaving section or if they may form downstream of the weaving section once the problem is solved, a much longer section could be needed to fully evaluate the implications of the solution. This ability to evaluate the upstream/downstream interactions is one of the primary reasons for the existence of freeway simulation models.

- Minimum study area length - A key criterion to defining the study area is the interrelationship among congestion problems within a corridor. If, in the no-build condition for the horizon year, traffic queues are expected to extend continuously for a certain length, mat will define the minimum study section. The study area should extend at least one-half mi (0.8 km) downstream of existing bottlenecks or anticipated future bottlenecks. It is also important not to just terminate the study area at a jurisdiction's border, but to rely on the traffic interrelationships as a primary criterion.

- Selecting corridor termini - Often, the corridor will have natural boundaries on which its definition can be based. For example, a natural corridor would be a freeway with one end in the suburbs and the other terminating downtown. Such a corridor may also have natural intermediate breaks, such as a major circumferential roadway, river, or mountain range. However, if congestion extends (or is expected to extend) across these boundaries, the corridor cannot be terminated there, but must be carried past the point where congestion is expected to extend.

- Corridor width - Depending on the physical layout of the corridor, the corridor width can include only the freeway or may include the freeway plus several parallel

arterials or other freeways. If parallel arterials are nearby or can be expected to be built nearby, the arterial should at least be thought of as a component of the project development or operational analysis process. One of the solutions to the freeway could, in fact, be improving the flow on the arterials or constructing new parallel roadways. In many cases though, the freeway alone would be sufficient.

Analysis time periods:

- Selection of peak periods to study - Corridor studies for the analysis of design and operations will almost always be addressed toward the peak weekday periods. The peak period should be selected to include not only all hours during which congestion currently exists, but hours during which congestion could occur in the horizon year. This implies a considerably longer simulation period than might otherwise be required. Simulation must begin well prior to the beginning of the congested period; it should never begin in the middle of a congested period. Therefore, the simulation time should be initiated at least 30-min prior to the expected onset of congestion to ensure that this transition period between no congestion and congestion is properly simulated. Beginning the simulation after the onset of congestion will produce serious errors in the results. The necessary time for beginning the simulation can be determined from examination of the voium8 data for the horizon year, determining how close the volume per lane is to reaching capacity. If the simulation is being used for highway design, it should extend at least 1 h past the peak 15-min period. Normally, though, the simulation should not end until the simulated congestion dissipates in the horizon year for the no-build condition. This is particularly important if the purpose is to compare vehicle miles, vehicle hours, emissions, and other aggregate peak period statistics (i.e., a cost effectiveness-type evaluation). This could, in many cases, be 1 h or more beyond the current end of the peak period.

- Combination of time periods and directions to be simulated - If the primary problem being addressed is freeway design, one peak period per direction is often sufficient to establish the design requirements. While the basic number of lanes is normally the same for both directions, ramp configurations may be such that the design in one direction will not mirror the design for the other. Therefore, the simulation of both directions is normally required. Unusual traffic patterns or similar levels of traffic volume may require a second peak period to be analyzed, but this is not usually the case.

Task Products:

- Decisions documented on horizon year to be simulated, study area (described in text or shown on a map), and analysis time periods and directions.

Task 5: Select Analysis Tools

Task Objective: Select the analysis method (simulation and/or *Highway Capacity Manual)* that will provide the information necessary to conduct the evaluation.

Task Input:

- Measures of effectiveness mat must be generated.
- Study objectives.
- Definition of horizon year, study area, and time periods.
- Assessment of data available to conduct the analysis.
- Amount of time available to conduct the analysis.
- Level of technical expertise available to conduct the analysis.

Task Activities:

Chapter 3 provided a basic description of the analysis tools falling within the purview of this report. These include the freeway simulation models FREFLO, FREQ, FRESIM, and the freeway procedures in the 1985 *Highway Capacity Manual* (HCM). Each of the models have strengths and weaknesses in dealing with various aspects of the planning, design, and operational analysis process. Chapter 4 was entirely devoted to providing guidance in the selection of the appropriate model or models for evaluating a freeway corridor. Table 3 in chapter 4 presented a qualitative evaluation of each model's ability to address specific geometric and operational situations. The text of Chapter 3 provides substantial Information on how, if at all, each model can be used to address specific geometric and operational strategies and situations.

The selection of the model will depend primarily on its ability to evaluate the feature of interest, and any other limitatlons introduced by the characteristics of the study area or freeway corridor itself. The technical report, a companion to this final report, provides a more detailed evaluation of the strengths and weaknesses of the models in addressing these conditions, for purposes of recommending model enhancements.

Task Output:

- Recommendation of the model or combination of models required.

Task 6: Establish Operational Standards

Task Objective: Define acceptable levels of traffic operation for the corridor.

Task Input:

- Operational objectives and policies established for the region or for the corridor.
- Input from policy-makers for the specific study.

Task Activities:

The primary activity in this task is establishing the operational standard that is desired to be achieved in the corridor. The most commonly used operational standard is a level of service standard. A sample standard could be reflected in a statement such as "achieve level of service D operation on all roadways in the corridor at the horizon year." Other operational standards could also be specified, such as desired speed levels (similar to level of service), or limiting the duration of congestion. This discussion is not meant to imply that eliminating congestion (e.g., requiring the freeway to operate at level of service at all times) is an appropriate operational standard. For example, emphasis on transit and HOV operations in the corridor may suggest that a lower level of service standard for non-HOV vehicles be established than has traditionally been used in the past.

Task Output:

- Designation of operational standards to be achieved.

Task 7: Identify or Establish Geometric Standards

Task Objective: Specify geometric standards to be uaed for freeway deslgn.

Task Activities

Most freeways are State highways with well-established geometric standards. These will serve as the guidance for making design decisions later in the project However, several fundamental questions must be asked as the project proceeds, such as:

- Is it possible that reduced geometric standards will need to be entertained to satisfy cost and environmental requirements? This is a frequently debated and often controversial issue mat must be worked out through the process of alternatives evaluation and financing.

- Are there other possible design exceptions that may need to be considered because of the uniqueness or nature of this project? These could be due to considerations of HOV facilities, ramp metering, or other uses.

Task Products:

- Set of geometric standards to be used for the corridor (usually a reference to existing documents that apply for that area).

Task 8: Collect Traffic Data

Task Objective: Develop data on roadway geometry, existing traffic volumes, vehicle occupancy, traffic speeds and queuing, traffic accidents, and other data that can be uaed to evaluate existing problems and validate the simulation models.

Task Input:

- Measures of effectiveness selected in task 7.

- Existing reports and studies conducted in the corridor.

- Existing traffic volume records from the responsible agencies.

- Recent vertical aerial photograph of the corridor.

- As-built plans for the corridor (or similar set of plans that provide distances between on-ramps and off-ramps, horizontal curvature, vertical curvature, number of lanes, and lane/shoulder widths).

- Guide sign locations (for FRESIM only).

- Computer spreadsheet and graphics packages for displaying the information.

<u>Task Activities</u>:

Many times, the corridor under study has a past history of analysis, if only on a qualitative level. While past studies and concerns should not bias the approach or findings of the current study, the analyst must at least be familiar with issues that have arisen or have been analyzed previously. Collection and review of previous reports and correspondence will put the project in proper perspective. During this task, phone calls, letter requests, and interviews may be needed to identify potentially relevant existing reports.

In addition to the existing reports, the following data will be necessary:

Traffic counts:

- Machine counts should be taken on the freeway (or counts from a surveillance system) at every on-ramp and off-ramp, on the mainline at the beginning of the study area, on the mainline at the end of the study area, and on the mainline at 3-mi to 5-mi (4.8 km to 8 km) intervals in between, depending on the type of model being used. Counts should cover the entire simulation period as defined in Task 4 and should be available in 15-min increments.

- Ideally, the traffic counts should be collected on the same day, but this is often not possible. Normally restricting collection to Tuesday, Wednesday, and Thursday will minimize these differences. In addition, great care must be taken to ensure that the volumes are not significantly affected by incidents within the section to be simulated. Even incidents well upstream or downstream of the section can affect volume within the section, and this should not be used.

- If the arterial is being simulated, directional link volume counts will be needed in 15-min time periods for each section. These are usually collected using machine counts. However, counts need not be conducted on each segment, but can be estimated from nearby segments, if budget limitations exist.

- Auto occupancy counts (at least 100 vehicles) will be needed at each on-ramp and at the mainline entry and exit points (auto occupancy counts may not be needed if HOV analyses will not be conducted). If the budget is constrained, estimates at ramps based on mainline data may need to be used. Ramps could also be counted selectively and estimates of auto occupancy generated for the ramps not counted.

- Display of volume data. Figure 15 shows a sample spreadsheet with traffic volume data from a sample section. The format is such mat ramp volumes are used to compute mainline volumes between each interchange. It is an excellent tool to conduct logic checks of the collected data. Just because the cumulative volumes do not balance from ramp to ramp does not mean that a problem exists. During the formation of traffic congestion, density within the congesting section is increasing. In this case, the total input to a given section will be greater than the

HOURLY VOLUME

																									MAINLINE
ON	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	OFF	ON	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	OFF
8001	8040	8041	8042	8043	8044	8045	8046	8047	8048	8049	8050	8051	8053	8052	8054	8055	8056	8057	8058	8059	8060	8061	8062 8063 8064 8037			◄——Node numbers
1	2	1	3	2	4	3	5	4	6	5	7	6	7	8	9	8	10	9	11	10	12	11	13 12 14 13 CHECK			

3:00-3:15	2963 413 289 1662 289 579 581 1767 539 712 845 1428 1791 2852 1406 1580 1857 1211 1407 583 744 401 950 472 1065 1501 3549 3549
3:15-3:30	3396 449 383 1529 384 778 434 1796 472 518 850 1725 1979 2597 1202 1741 1696 1152 1568 583 785 406 941 500 989 1496 4193 4193
3:30-3:45	4347 538 461 1383 456 781 627 1991 473 541 979 1758 2052 2757 1434 1556 1862 1168 1702 585 824 406 918 511 912 1490 4386 4386
3:45-4:00	3258 493 533 1255 534 1156 616 2101 478 677 873 2130 1895 2213 1200 1719 1984 1196 1867 584 868 400 905 528 851 1485 4565 4565
4:00-4:15	4419 489 656 1120 658 874 645 2270 484 549 952 1791 1946 2758 1318 1768 2007 1300 2124 545 952 245 852 545 817 1473 4063 4063
4:15-4:30	3898 750 745 984 745 1096 695 2218 384 584 867 2158 1784 2681 1345 1757 1823 1429 2296 544 977 245 841 556 768 1473 4431 4431
4:30-4:45	4604 718 784 839 784 841 750 2624 372 656 967 2086 1552 2608 1418 1862 1757 1189 2380 540 1012 249 828 567 690 1468 5177 5177
4:45-5:00	3874 600 890 800 889 994 795 2391 367 623 922 2558 1473 2429 1234 1980 1829 1591 2642 540 1072 244 823 556 652 1468 4670 4670
5:00-5:15	3653 695 896 827 895 929 923 2424 360 505 935 2514 1134 2346 1607 2107 1640 1574 3041 506 1149 250 1035 528 640 1468 4593 4593
5:15-5:30	3375 556 778 750 778 885 862 2447 416 567 789 2719 1212 2292 1312 2112 1679 2057 3237 505 1123 251 1006 500 550 1334 4648 4648
5:30-5:45	2929 453 673 812 673 834 1001 2291 384 544 718 2651 1167 2451 1183 2202 1573 1919 3452 511 1106 250 995 472 527 1195 3526 3526
5:45-6:00	4382 451 573 841 567 789 790 2186 334 473 905 1735 1172 2775 1361 1852 1646 1641 3014 506 1125 250 996 433 493 1001 3531 3531
6:00-6:15	3376 438 445 890 434 605 628 2073 339 473 909 1573 1195 2146 1218 1590 1724 1261 2213 361 939 244 989 389 466 862 2846 2846
6:15-6:30	3480 406 911 955 317 618 423 1851 378 490 939 1575 1518 2947 1042 1584 1800 1145 1778 356 780 245 1008 344 473 584 2023 2023
6:30-6:45	2579 285 228 996 228 612 472 1652 368 542 878 1407 1336 2668 1096 1534 1717 989 1400 361 612 245 1047 323 467 278 1498 1498
6:45-7:00	2145 301 239 1056 245 607 417 1432 356 514 810 1336 1329 2573 1257 1502 1744 990 959 355 479 245 1125 278 463 278 1557 1557

MAINLINE VOLUMES   Ramp volume inputs

																																			MAINLINE
SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG	SEG EXIT
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35/36

3:00-3:15	2963 3376 3376 3087 4749 4460 5039 4538 6305 5766 6478 5633 5633 7061 5270 5270 2418 2418 2418 3824 3824 5404 5404 5404 3547 4758 3351 3934 3190 3591 2641 3113 2048 3549 3549
3:15-3:30	3396 3845 3845 3462 4991 4607 5385 4951 6747 6275 6793 5943 5943 7668 5689 5689 3092 3092 3092 4294 4294 6035 6035 6035 4339 5491 3923 4506 3721 4127 3186 3686 2697 4193 4193
3:30-3:45	4347 4885 4885 4424 5807 5351 6052 5425 7416 6943 7484 6505 6505 8263 6211 6211 3454 3454 3454 4888 4888 6444 6444 6444 4582 5750 4048 4633 3809 4215 3297 3808 2896 4386 4386
3:45-4:00	3258 3751 3751 3218 4473 3939 5095 4479 6580 6102 6779 5906 5906 8036 6141 6141 3928 3928 3928 5128 5128 6847 6847 6847 4863 6059 4192 4776 3908 4308 3403 3931 3080 4565 4565
4:00-4:15	4419 5108 5108 4452 5572 4922 5796 5151 7421 6937 7484 6534 6534 8325 6379 6379 3621 3621 3621 4939 4939 6707 6707 6707 4700 6000 3876 4421 3469 3714 2862 3407 2590 4063 4063
4:15-4:30	3898 4448 4448 3903 4887 4142 5238 4543 6761 6377 6961 6094 6094 8252 6468 6468 3787 3787 3787 5132 5132 6889 6889 6889 5066 6495 4199 4743 3766 4011 3170 3726 2958 4431 4431
4:30-4:45	4604 5322 5322 4538 5377 4593 5434 4684 7308 6934 7592 6625 6625 8711 7159 7159 4551 4551 4551 5969 5969 7831 7831 7831 6074 7263 4883 5423 4411 4660 3832 4399 3709 5177 5177
4:45-5:00	3874 4474 4474 3584 4384 3495 4489 3694 6605 5718 6341 5419 5419 7977 6504 6504 4075 4075 4075 5309 5309 7289 7289 7289 5460 7051 4409 4949 3877 4121 3298 3854 3202 4670 4670
5:00-5:15	3653 4348 4348 3452 4279 3384 4313 3390 5814 5434 5959 5024 5024 7538 6404 6404 4058 4058 4058 5665 5665 7772 7772 7772 6132 7706 4665 5171 4022 4272 3237 3765 3125 4593 4593
5:15-5:30	3375 3931 3931 3153 3903 3125 4010 3148 5595 5179 5744 4957 4957 7676 6464 6464 4172 4172 4172 5484 5484 7596 7596 7596 5917 7974 4737 5262 4119 4370 3364 3864 3314 4648 4648
5:30-5:45	2929 3382 3382 2709 3521 2848 3682 2681 4972 4588 5132 4414 4414 7065 5898 5898 3447 3447 3447 4630 4630 6832 6832 6832 5259 7178 3726 4237 3131 3381 2386 2858 2331 3526 3526
5:45-6:00	4382 4833 4833 4260 5121 4554 5343 4553 6739 6405 6878 5973 5973 7708 6536 6536 3761 3761 3761 5122 5122 6974 6974 6974 5328 6969 3955 4461 3336 3586 2590 3023 2530 3531 3531
6:00-6:15	3376 3814 3814 3369 4259 3825 4430 3802 5875 5536 6009 5020 5020 6593 5398 5398 3252 3252 3252 4470 4470 6060 6060 6060 4336 5597 3384 3745 2806 3050 2061 2450 1984 2846 2846
6:15-6:30	3480 3886 3886 3575 4530 4213 4831 4408 6259 5881 6371 5432 5432 7007 5489 5489 2542 2542 2542 3604 3604 5188 5188 5188 3388 4533 2755 3111 2331 2576 1568 1912 1439 2023 2023
6:30-6:45	2579 2864 2864 2636 3432 3404 4016 3544 5196 4828 5390 4512 4512 5919 4583 4583 1915 1915 1915 3011 3011 4545 4545 4545 2828 3817 2417 2778 2166 2411 1364 1687 1220 1498 1498
6:45-7:00	2145 2446 2446 2207 3263 3018 3625 3208 4640 4284 4798 3968 3988 5324 3995 3995 1422 1422 1422 2679 2679 4181 4181 4181 2437 3427 2468 2823 2344 2589 1464 1742 1279 1557 1557

Calculated mainline volumes (segment 1 is actual)

Figure 15. Sample volume spreadsheet for preparing, balancing, and checking input data.

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output of that section. When congestion is receding, the total output will be greater than the input to a section. This should be kept in mind when reviewing the reasonableness of the volume data. Forcing the input and output to balance may actually be detrimental to achieving a reasonable model validation. However, some datasmoothing may be needed if the input and output are not logically consistent with the increases and decreases in congestion. Possible errors to check for include entry of volume data into the wrong ramps and volumes affected by incidents (e.g., a major accident occurred on the facility or on a nearby facility that significantly affected traffic volumes in the corridor).

- Another concern in collecting the volume data is that the data reflect true demand, and not be affected by downstream capacity problems. The ramp counts should be conducted at the upstream end of both on-ramps and off-ramps, to reduce the chances of the volume counts being affected by either queues backing up from traffic signals, from the mainline, or from ramp meters, where they exist.   If, for example, metering strategies are being tested, counts conducted at the meters will under-represent the true demand volume. Counts need to be conducted where vehicles enter the ramp from the arterial.

- Vehicle classification counts: A single count to establish the mainline truck percentage will often suffice. However, at least two representative ramps should also be counted, as the truck percentage on the ramps may differ from the truck percentage on the mainline. Ramps where the truck percentage is expected to be considerably higher than the norm should also be counted. The truck definition in the count should coincide with the truck definition in the model to be applied.

- Often, there is a question of whether traffic data collected prior to the initiation of the study is valid. This is particularly true for data that is 3 or more years old. While in using data already collected is economical, the analyst must have complete confidence that the data are valid. Factoring counts from 2 years in the past would be considered reasonable. Three years may be acceptable if growth is slow.   However, if there is any question about the validity of the data, it should not be used. The immediate economies are far less of a concern than the potential for the entire study to be challenged, endangering the usefulness of the results.

Traffic speeds and queuing:

- The ideal is to have a full set of existing speed contours that show speeds in 15-min time periods for each section of freeway. Unless the section has an extensive electronic surveillance system, this is seldom possibie. If a surveillance system is not available, at least one speed profile for the peak congestion period should be obtained using travel time runs. Speeds should be computed between each ramp

exercised in selecting the travel time path (i.e. travel lanes), as previously discussed in the section on model calibration and validation in chapter 1.

- A queue contour of existing conditions should be constructed based on available travel time data and on input from individuals knowledgeable of the day-to-day corridor operation. These should be individuals that regularly drive or observe the corridor. Consultation with the local radio traffic reporting service to identify locations of recurring congestion is often helpful.

Auto occupancy:

- Where auto occupancy data are needed, specify the percentage of one-person, two-person, and three-or-more person occupancy vehicles by ramp and for the available mainline locations.

Arterial speed and capacity data:

- If the arterial is also being simulated, some knowledge of the operating speed on the arterial is important. This can be estimated using an assumed freeflow speed and calculating delays at signalized intersections (e.g., using procedures in chapter 11 of the HCM), or through travel time runs on the arterial during the period being simulated.

- Arterial capacity can be estimated using the procedures in chapter 9 of the HCM. FREQ is designed to lump the capacity of several parallel arterials into an aggregate capacity. The data requirements for FREQ arterial analysis are small, but the level of simulation detail is relativety crude. FREFLO can be integrated with arterial models in the TRAF system (CORFLO level 1, CORFLO level 2, and NETSIM), and integration of arterial models with FRESIM is being tested. The level of information needed to run the models vanes substantially. NETSIM requires the most data.

<u>Task Products</u>:

- Table showing ramp and mainline volume by 15-min time periods for each section of freeway.

- Table showing auto occupancy by ramp and for mainline entry and exit points.

- Queue contour diagram for the freeway mainline.

- At least one speed profile for the most congested period on the mainline.

- Arterial volume in 15-min time periods.

Task 9: Document Existing Geometrlcs and Operations

Task Objective: Document existing roadway geometry and operatlonal strategies already employed.

Task Input:

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- Prior reports on the corridor.
- Regional and corridor data bases.
- Existing aerial photography.
- As-built plans.
- Existing operational strategies and practices.

Task Activities:

This task defines the current physical conditions of the freeway corridor and documents existing operational strategies. Geometric items to be documented include:

- Length of each freeway and arterial section to be studied from ramp to ramp or from intersection to intersection.

- Vertical grades and grade length (grade length measured from vertical point of intersection (VPI to VPI).

- Length of each section in feet

- Horizontal curvature and super-elevation (for FRESIM only).

- Number of lanes by section.

- Lane and shoulder width.

- Existing photo log or video log, if available.

Features to be documented for freeway operations include:

- Existing informational signage (primarily for FRESIM only).

- Existence of HOV priority treatments on either the ramps or mainline.

- Existence of ramp metering systems.

- Existing timing at ramp meters.

- Existing incident management strategies (and incident type distribution, duration, and seventy, if an incident management evaluation is to be conducted).

- Existing surveillance system capabilities.

- Existing variable message signs and other motorist information systems.

- Existing truck restrictions.

- Other existing restrictions that could influence traffic behavior.

The existing geometry of the freeway should be documented in a graphic, similar to that shown in Figure 16. This will provide the essential information from which the network coding will be done. For FRESIM, the existence and length of acceleration and deceleration lanes is an issue, and the analyst may wish to show these on the diagram, although they may still be unscaled. Peak hour volumes should be included to provide an indication of which ramps are most heavily used and how close they may be to capacity. The simplest way to begin to construct the diagram is from a recent aerial photograph. Section lengths can then be determined through measurements from the as-built plans. In some cases, the as-built plans may be difficult to work with, because the freeway was reconstructed on a spot basis over a period of time and there is no single set of geometric plans that provides a good implement for measuring between interchanges. A signing or striping plan, if available, may provide a more convenient set of plans, and will also include lane designations. Some DOTs have computerized geometric databases. For the development of a simulation model, however, use of scaled aerials is usually sufficient for determining section lengths and defining lanes. An error in distance of as much as 50 ft (15 m) is typically inwnsequential to the result of the analysis. A profile will be needed for coding grades.

At least one trip should be made by the analysis staff through each section of roadway being analyzed to verify conditions. A videotape is a cost-effective way of documenting conditions for later reference in the project. For purposes of documenting geometrics, the tape should be made during the off-peak period.

Task Output:

- Comprehensive lane diagram of the freeway and any arterials being analyzed.
- Brief memorandum documenting existing operational systems.

DARK LINES INDICATE SUBSECTIONS SIMULATED BY FRESIM FOR THIS STUDY
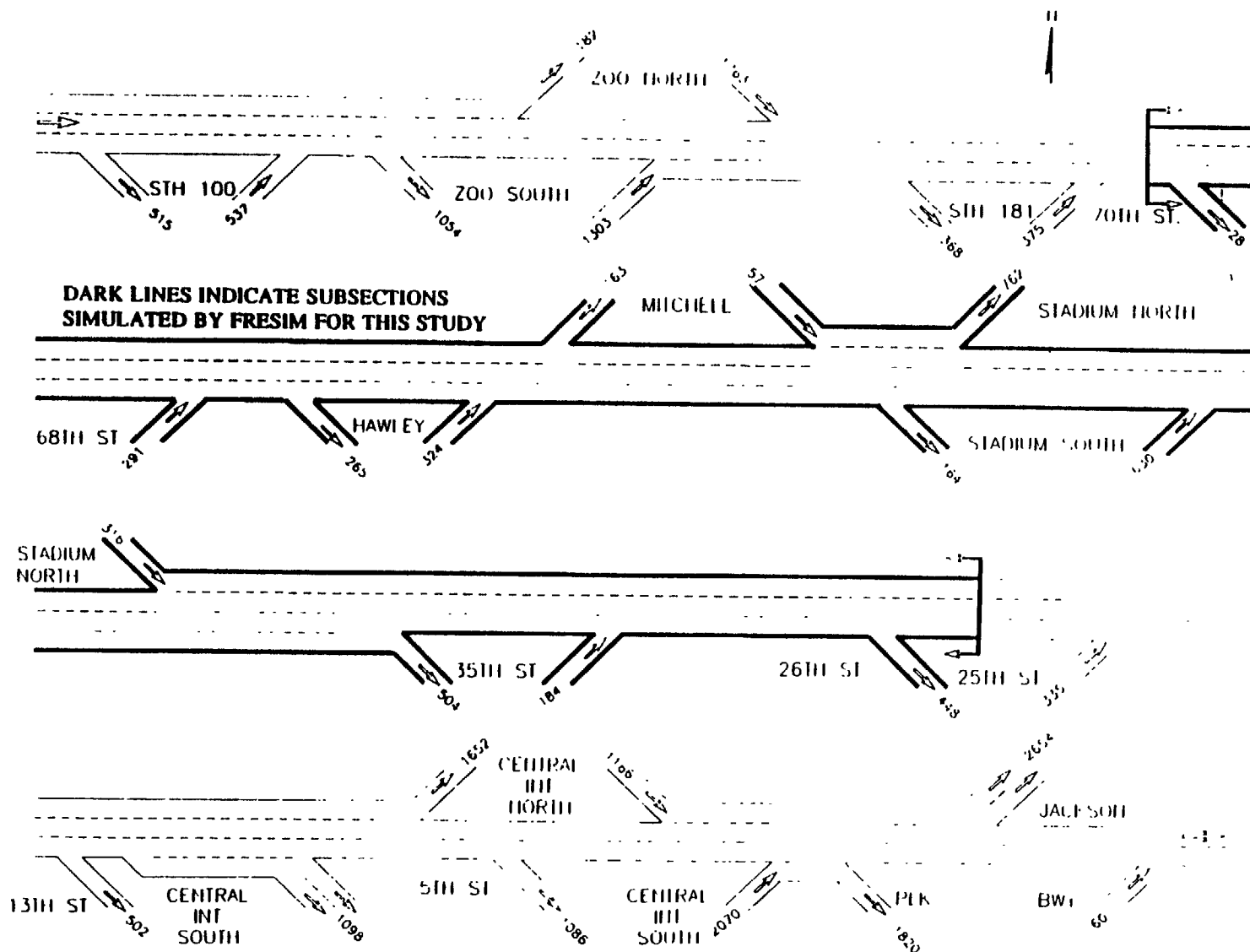
Source: Milwaukee I-94 case study. Numbers are 1989 peak hour volumes.

Figure 16. Sample lane diagram.

Task 10: Create Model Setups

Task Objective: Enter the necessary information Into the computer models.

Task Input:

- Existing geometries and operations.
- Existing traffic data.
- Simulation model software and documentation.
- Study area and time periods defined in task 4.

Task Activities:

Substantial effort must usually be invested in gathering data before the simulation model can be created. As a rule of thumb, the process of evaluating a corridor can be divided into three roughly equivalent levels of effort: collection of data (task 8), validation of the models (primarily tasks 9 through 11), and alternatives analysis (phases 2 and 3).

While the entry of geometric and traffic data into the model can usually be done in a short period of time (usually less than 1 day), it is one of the more important parts of conducting a simulation analysis.   Mistakes made at this point may not be detected easily later on, and care exercised In this task will usually save time and money in the long run. For this reason, it is wise to double check Input prior to conducting any simulation modeling.

Data entry is easier for some models than for others. For example, FREQ requires the simple input of 15-min volumes (or volumes for other user-defined time periods) for both on-ramps and off-ramps.   FREFLO, on the other hand, requires direct volume input for on-ramps, but an "exit fractions" percentage for defining exit ramp volumes. This requires additional calculations, and can only be specified to the nearest percentage point of mainline volume.   If the mainline volume is 6,000 vehicles per hour, the closest the analyst may be able to get to matching off-ramp volume is 30 vehicles. This is probably within the realm of volume variation on a ramp, and should not pose a significant problem in the simulation itself.   FRESIM allows hourly counts to be used which are converted to percentages internally. Editing modules are available for all three models, making data entry easier and less error prone.

Typically, the data entry task can be given to an engineering analyst. However, it is sometimes useful, particularly for the initial involvement with simulation, for the engineer to work directly with inputting some of the data items into the model. This provides an increased appreciation for the task of data entry and for potential errors that could come into play. Ongoing improvements are being made to all of the models, with increased emphasis on user interfaces that make dealing with the models easier and errors less likely. FREQ has a useful method for checking the input to freeway geometry. This involves a simple graphic display

showing the number of lanes and location of on-ramps and off-ramps. If using FREQ, the analyst should print the graphic and compare it with the original lane diagram prepared (see figure 16, shown earlier).

Task Output:

- Coded networks.
- Other geometric and traffic characteristics coded into the model.

Task 11: Calibrate and, Validate Models

Task Objective: Verify that the slmulatlon models reasonably represent existing conditions.

Task Input:

- Model setups.
- Exisitng volume, queuing, and speed data.
- Validation strategy.

Task Activities:

An introductory discussion to model calibration and validation was provided in chapter 2. This material Will be partially repeated here, but also includes more detailed steps on the calibration and validation process.

The primary reasons for calibration and validation defined in chapter 2 are:

- It provides another possible check on glaring errors that may have been introduced in the model coding stage (even errors in the coding of existing geometrics).

- once complete, the validation provides an assurance to the analyst and to those making decisions based on the model, that the model can be relied upon to produce reasonable answers.

- It provides a way of checking the adequacy of the theoretical basis for the models. While this is more of a model development concern, it is an issue of which the model user should be aware and that may need to be brought to the attention of the model developer.

It is Important to recognize that the measurement of traffic characteristics in the field is a variable that has no single exact answer. Traffic Characteristics represent a sample from a population of days and peak periods. A difference between the validation and the measured traffic data could involve simply a variation in the data on the day or days for which it was sampled. As indicated in task 8, extreme care must be exercised in data collection so that the model is being developed from and its results are being compared to valid data representing the simulation period.

There are several key MOE's to be examined in confirming the validation of a model:

- Traffic volume at intermediate points on the mainline - If traffic volumes at on-ramps and off-ramps have been consistently measured on days that are similar in traffic volume characteristics (and during which no incidents have occurred), the volumes computed on the mainline at intermediate points in the freeway section should match reasonably well with the actual measured volumes. Actually, the extent to which these volumes will match can usually be determined in the volume spreadsheet even prior to having entered the data into the simulation model itself. However, matching the volumes developed from the input/output analysis against the actual measured mainline volumes is a good check. Discrepancies can indicate that either the ramp volumes or mainline volumes contained an error. If more than one mainline volume differs from the input/output analysis, then the more probable situation is that an error exists in the on-ramp or off-ramp volumes. It is important to remember that traffic will be accumulating within the freeway section as the congestion period is entered (i.e., input will be greater than output). When moving out of a congestion period, output will be greater than input.

- Queue contours - FREQ produces a queue contour directly. A queue contour can be indirectly derived from FREFLO and FRESIM by plotting a time/space contour of density, and setting a density threshold to be defined as a queue. of course, the density contour can be used directly as a comparison against known queuing patterns. While the actual and simulated queue contours will seldom match exactly, a review of the queue contour will be the most convincing evidence that the model represents actual traffic flow in the corridor. A typical threshold of density for defining a queue is 70 vehicles per ml per lane. FRESIM's surveillance and point processing capabilities can be used as an additional means to plot queue growth.

- Speed profiles and contours - FREQ also produces a speed contour, and similar plots can be indirectly derived from FREFLO and FRESIM. However, these are typically shown to the nearest 10 mi/h (16 km/h). A more detailed speed profile should be produced during the most congested period from both the actual travel time runs and from the simulation model. This will be another visual comparison of the model's predictive capability.

It is unusual to have a perfectly matching set of simulated and actual conditions the first time through a modeling run. Typically, between 5 and 20 runs may be required before an acceptable validation level is achieved. The next question is then, is "What model parameters are adjusted to achieve the required validation?" me answer to this vanes depending on the type of model:

- FREQ and FREFLO (the macroscopic models) - The primary parameter to be varied for these models is section capacity. Hopefully, only minor modifications to capacity are needed. Often, small adjustments can make Significant differences in the resulting queue contours or speed profiles, and several refinements will bring the contours or profiles into line. However, there are two areas where significant questions still exist in the adequacy of the procedures used to estimate highway capacity. At the current time, these questions revolve largely around weaving sections and significant upgrades. Currently, no capacity value is output from the *1985 Highway Capacity Manual* weaving procedures. The FREQ model uses the 1965 procedure as the basis, and FREFLO assumes that the user will be able to develop an adequate value. In addition, the FREQ model allows the user to either enable or disable the weaving analysis procedure. Through significant experimentation in this project, the preferred method is to disable the FREQ weaving analysis procedure and adopt a modified procedure. The suggested interim procedure, until better weaving analysis procedures are developed (with capacity values generated as output), is to use the curves shown in figure 17. These curves were derived from a series of simulations with FREQ but with the impact on capacity of weaving volume and length adjusted to temper the capacity reducing effect. These curves are more practical than theoretical, and have been found to provide a more reasonable result than using the 1965 HCM procedures directly. It is important that future research on weaving procedures produce a weaving area capacity value based on weaving volumes and weaving area length. Another possible method of dealing with the problem is to introduce a factor into the FREQ weaving capacity algorithm to allow the user to adjust the computed Capacity reduction. It is important that relationships between weaving volume, weaving area length, and capacity be developed so that the simulations are not merely dependent on a capacity value arbitranily selected by the user, but that the capacity value can change based on the geometric and traffic characteristics of that section in the future. In dealing with capacity on grades, it is suggested that the reduction computed in the existing highway capacity procedures be slightly tempered to make the capacity reduction less severe.

  A poor initial validation may also be attributable to input errors or inaccurate volume data- Therefore, the input data should be rechecked if significant validation problems occur. Modifying **the** capacity relationships to counter input errors is merely correcting a wrong with another wrong.

- FRESIM - An entirely different process is used for validating FRESIM. FRESIM has no capacity input; rather, capacity is an output, This is a fundamental difference between macroscopic and macroscopic models. Macroscopic models must assume that the user is able to accurately estimate capacity. This is not difficult for the existing condition, but it is debatable whether the analyst can accurately estimate capacity for an improved condition. The weakness of the weaving and ramp capacity procedures in the HCM has been referred to earlier. In FRESIM, the ability to accurately simulate the range of conditions rests on the Validity Of the microscopic car-following and lane changing relationships. If these relationships reflect reality, there is no reason to believe that the model will not produce reasonable results. However, some provision has been made in FRESIM to adjust these relationships. The user must adjust a set of "driver sensitivity factors" until the simulation output adequately represents existing conditions.
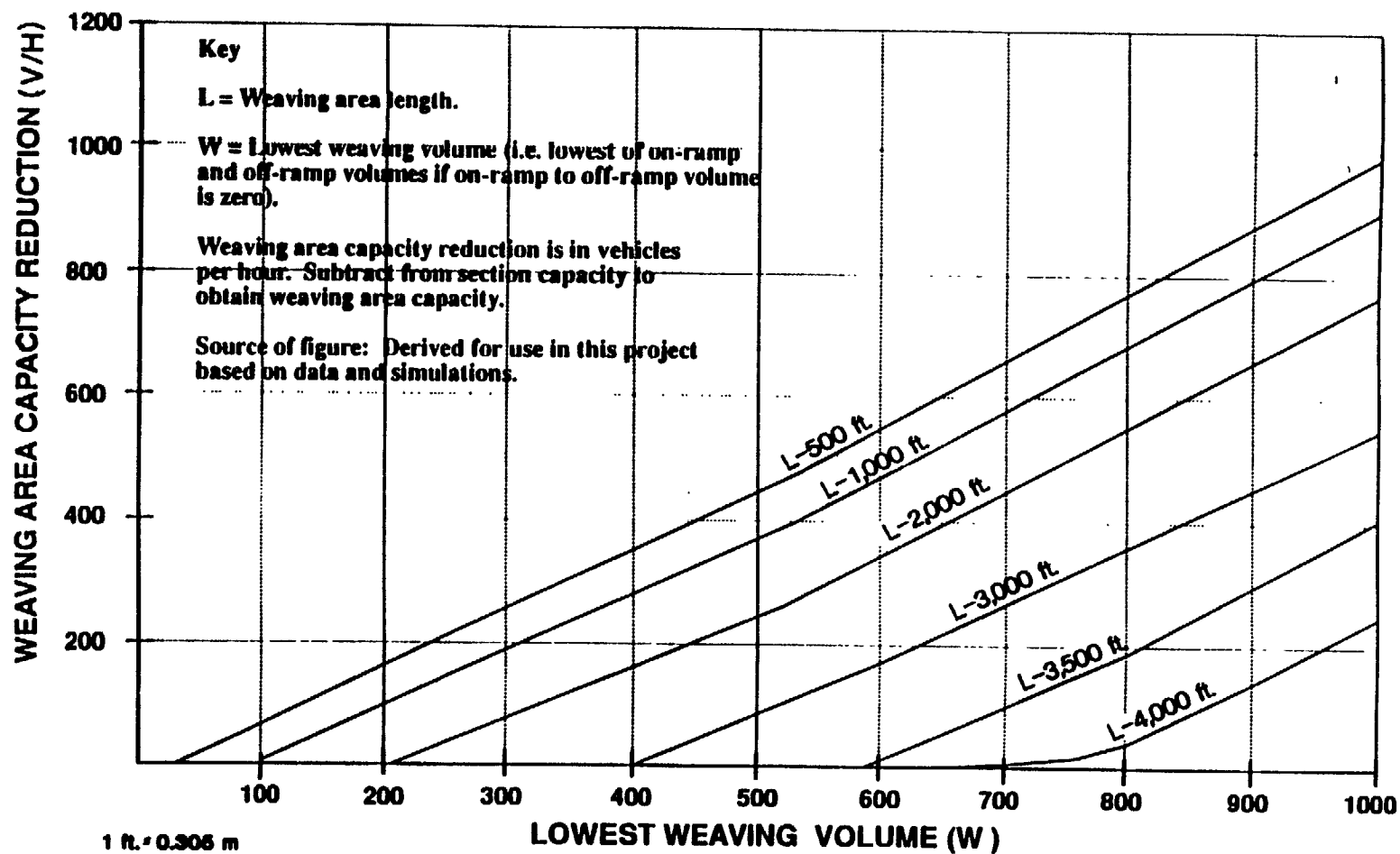
Figure 17. Relationship between weaving area capacity reduction, weaving area length, and lowest weaving volume.

Unfortunately, there is very little basis of experience in making these adjustments. It is a relatively tedious trial and error process. In conducting this process there are two variables: the proportion of drivers in each sensitivii level and the actual sensitivity levels of the drivers. In experience with FRESIM thus far, it is better to work with only one of these variables, and the sensitivity factors for each driver subgroup appear to be the easiest way to deal with the problem. The approach thus far has been to modify each driver subgroup up or down a level of driver sensitivity until the desired result is achieved.

Task Output:

- Comparisons of simulation model output with actual measures.
- A brief validation report documenting the comparisons and the process.

Task 12: Identify Problems and Possible Causes

Task Objective: To Identify specific congestion problem locations and to draw conclusions on what may be causing the problems to occur.

Task Input:

- Documentation of existing traffic conditions.
- Notes taken during field observation.
- Simulation model results.

Task Activities:

The identification of traffic problems and possible explanatory causes are actually two separate steps, but have been combined into one task because they are so intertwined. The problem can be viewed as a description of the location and extent of congestion, while the cause represents the reason the congestion exists. For example, the problem could be specified as a "queue developing on I-11 between the Third Street and Fourth Street interchanges," with the associated cause being a "short weaving section:"

The existing problem will usually be readily apparent. Often, the cause will also be fairly obvious, but there are occasions when causes are much more subtle. For example, an origin/destination relationship could be one of several contributing causes to a weaving problem. One obvious possible solution may include the geometric modification of the weaving section. However, modifying the access around a nearby shopping mall (which would reduce the weaving volume on the freeway) could more directly address the fundamental

cause of the problem and result in a much less costly solution than geometric modification of the freeway. This highlights the importance of not only observing the problems, but also thinking through the possible causes.

Chapter 5 was devoted to a presentation of geometric and operational strategies to solve specific freeway congestion problems. Task 12 uses this and other information to evaluate and document known problems and to associate each with a possible cause. Typical steps include:

- Visual observation of the corridor under congested conditions. There is no substitute for visual observation. In fact, insufficient first-hand knowledge of traffic conditions in the section could result in inadequately defining the problem, a poorly validated model, and subsequent criticism of the study.

- Photographic or videotape documentation of problems, if appropriate. This would be particularly important if public meetings are envisioned or if a significant number of the steering committee participants are unfamiliar with the corridor.

- Development and review of collision diagrams. Although the simulation models do not directly address safety, patterns of accident occurrence are not only important as part of problem identification, but may also be interconnected with the operational problems.

- Review of complaint records. Telephone calls and letters from citizens should be reviewed, both to gain an understanding of public concern as well as to trigger any additional thoughts the project team may have on existing problems.

- Listing of problems. The steering committee should, at one of its early meetings, provide an opportunity for members to voice specific wncems and to identify specific known problems. A composite list of problems, section by section, would be a product of that meeting.

- Identification of possible causes. This should be a topic of the same steering committee meeting at which problems are dicussed. Many of the causes will be obvious. Others will be more subtle and may be linked not just to the geometric design but, to the characteristics of the traffic flow itself.

- Creation of a problem/issue summary. This can usually be done on the lane diagram. Alternatively, a simple table can be developed describing the problems on a section-by-section basis.

Task Products:

- An existing conditions and problems report, containing text descriptions, a problem/issue summary graphic, and a list of problems and possible causes.

- Material produced in intermediate steps, such as collision diagrams and photo documentation.

PHASE II: SHORT-TERM ANALYSIS

Task 13: Identify Candidate Short-Term Strategies

Task Objective: Determine which geometric and operational strategies may be appropriate as solutions for Implementation within the next 1 to 5 year time period.

Task Input:

- Results from task 12, identifying problems and possible causes.
- Description of possible strategies contained in chapter 5 of this document.

Task Activities:

Task 13 marks a significant milestone in the process of evaluating improvements for a freeway corridor. It Is possible that short-term improvements may be identified that will maintain mobility for an interim period while initiatives for developing and financing long-term improvements are undertaken. It may also be, however, that the strategies implementable in the short term are the only ones that are necessary (or the only ones that are desirable) to achieve the defined corridor objectives. This could be the case, for example, with a freeway that has virtually no opportunity for widening. The only alternatives with realistic possibility of implementation may be operational alternatives such as freeway surveillance and control systems or incident management. These decisions would be made in task 13. The candidate strategies would ordinarily be identified first by the technical staff most heavily involved in the project, followed by meetings with representatives from a variety of agencies to review the suggested candidate strategies and to develop others, where appropriate.

It is difficult to develop a systematic procedure that will automatically indicate the proper strategy to be applied to a particular problem and cause. Agency staff are certainly capable of generating strategies just based on experience and logic, to an extent. However, there is also value in referring to a comprehensive list of strategies, associated with problems and causes, that can be used as a form of checklist as an agency thinks through the process. Such a checklist or library of strategies can be used as an aid in insuring that strategies having potential benefit are not overlooked. Chapter 5 contains such a list It Is also here that the analyst and invoived agency representatives may wish to refer to various texts that have been developed dealing with these issues, including the *A Policy on Geometric Design* of Highways and Streets (American Association of State Highway and Transportation Officials, 1984), State and local design criteria, and special reports on freeway design and operation (e.g., the *Urban Traffic Controls Systems Handbook,* - FHWA, 1990). Short-term strategies would typically focus on operational improvements.

Task Output:

- Initial comprehensive listing of candidate improvement strategies for the next 1 to 5 year period for implementation.

- A refined list of strategies for which simulation and evaluation is proposed, based on interactive discussion among the involved agencies.

Task 14: SImulate Short-Term Strategies

Task Objective: **Use the simulation models and associated analytical tools to produce the measures of effectiveness that will be used to evaluate the relative benefits and required design features of the short-term strategies.**

Task Input:

- Candidate short-term strategies.
- Validated simulation models.
- List of MOE'S to be produced.

Task Activities:

This task represents a major component of the technical analysis to be accomplished. The approach to the simulation will largely depend on the nature of the strategies to be evaluated and the capabilities of the individual models being used. Chapter 4 previously presented a basic simulation approach for each type of strategy. In some cases, procedures may be required that the models were not designed to accommodate. For example, in simulating the effect of adding a lane by reducing the lane width and taking part of a shoulder, none of the models have a variable representing widths of lanes and shoulders. This would have to be represented by modification of capacity for FREFLO and FREQ and by variation of the driver sensitivity factors in FRESIM.

Because models generate large quantities of output rather quickly, it is important to be organized in the approach to conducting the runs.   tf the analyst does not exercise good discipline in labeling model runs, for example, the result may be confusion and becoming unnecessarily engulfed in a sea of paper. An important modeling practice is to always modify the labels identifying a model run (a capability provided by all the models), even if one thinks that he or she will remember what the run represented. The label should Include an output file name that has a meaningful relationship to the condition being evaluated. The file name should include characters distinguishing the location, direction, time period, and scenario. For example, 195NA10C.OUT could represent l-95 northbound in the morning peak period for 2010 alternative C. Figure 18 shows a cover sheet that can be used to provide additional

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FREEWAY SIMULATION SUMMARY SHEET

LOCATION _____   DATE OF RUN _____

DIRECTION _____   TIME OF RUN _____

TIME PERIOD _____   ANALYST _____

YEAR/SCENARIO _____

MODEL TYPE _____

INPUT DATA FILE(S) _____   LOCATION IN DIRECTORY _____
CONTROL FILE _____   LOCATION IN DIRECTORY _____
OUTPUT DATA FILE(S) _____   LOCATION IN DIRECTORY _____

COMMENTS: _____
_____
_____
_____
_____
_____
_____

SUGGESTIONS FOR NEXT RUN: _____
_____
_____
_____
_____

Figure 18. Sample freeway simulation summary sheet

documentation for any given model run. It provides space for naming input and output files, the nature of the scenario, and comments on the result (including possible ideas on what is needed for the next run). While such a system of documenting runs may at first seem to be bothersome, it inevitably saves time in the long run. Memories of exactly what was done on a simulation run can quickly fade, and they may need to be referred to months later. It is often possible to defer printing material out and to save it under an organized system of diskettes or tape backups**.**

Formatting the resulting information in an understandable way can be one of the most important aspects of the study. Summaries will need to be created for the steering committee that meaningfully convey the relative effectiveness of the various strategies and the extent to which the solutions achieve the corridor objectives originally established. Also important will be preliminary estimates of cost.

Table 7 shows a simplified table of order-of-magnitude benefits and costs of incident management strategies from the New York case study. The vehicle hours of delay saved were developed based on simulations-of a range of incident conditions. Intermediate tables and graphics were also prepared showing average incident durations under existing and improved incident management scenarios and vehicle hours of delay saved for each specific incident management strategy.

Task Products:

- A comparison of MOE's among the alternatives. Charts and tables should be prepared that clearly present the information to the steering committee for review.

- A brief memorandum may be needed transmitting and interpreting the information. However, handouts given to members at the meeting may be appropriate, depending on the level of formality and timing of the meeting.

Task 15: Evaluate Results

Task Objective: **Determine whether the simulation indicates that the improvements will achieve operational objectives for the corridor, and define the optimum alternative.**

Task Input:

- MOE's produced through the modeling process.
- Corridor operational objectives.
- Decision-making structure for agency staff and elected officials.

Table 7. Sample summary table of benefits and estimated costs of operational strategies from New York case study.

Strategy	Annual $Benefit[1]	Order-of-Magnitude Capital Cost[3]	Annual Order-of-Magnitude Main/Oper. Cost	Benefit/Cost Ratio (Approx.)[8]	Comment	Recommended Priority
Loops only	$1.5 million	$1.5 million	$150,000	Moderate	Detection needed to provide data to motorist info. system.	Moderate
Close Circuit TV only	3.0 million	24 million	300,000[6]	Moderate	CCTV has other benefits that cannot be quantified.	High
Loops & CCTV	3.5 million	3.9 million	450,000	Moderate	If loops and CCTV not done together, cost of either by itself will be higher than shown.	High
Additional wreckers	3.5 million	.....	600,000	High	Wilt likely need to be done by franchise tow.	High
Acc. Invest. sites	2.0 million	0.5 million	100,000	Moderate	Security is a problem. Unsure if adequate sites available	Not Recommended
Access Points	1.2 million	0.4 million	100,000[7]	High	Design to prevent abuse by public and to maximize safety.	Moderate
Lane Control	1.0 million	1.2 million	50,000	Low	Questionable if drivers will observe signs during incident.	Low
Cellular Call-in	1.0 million	Negligible	50,000	High	Will require monitoring of phones.	High
Variable message signs	2.5 million	1.6 million[4]	250,000[6]	Moderate	Significant commitment required to generate quality info.	Moderate

Table 7. Sample summary table of benefits and estimated costs of operational strategies from New York case study (Contlnued).

Strategy	Annual $ Benefit[1]	Order-of-Magnitude Capital Cost[3]	Annual Order-of-Magnitude Main/Oper. Cost	Benefit/Cost Ratio (Approx.)[8]	Comment	Recommended Priority
Highway advisory radio	2.5 million	1.1 million[4]	250,000[6]	Moderate	Significant commitment required to generate quality info.	Moderate
Toll processing	1.0 million[2]	Unknown	Unknown	Unknown	Will need to be determined on basis of management efficiency more than delay reduction.	

Footnotes (both pages):
1   Extrapolated from morning peak perbd analysts to include all time periods.   Based on $8 per vehicle-hour of time
2   Delay reduction benefits only. Does not include savings due to improve efficiency.
3   Communkations and central hardware/software are required for many of the strategies. These costs are allocated in approximate proportion to the individual costs for loops, CCTV, lane control, and signs. Total communications and central hardware costs are estimated to be $4 million.
4   Costs include a significant proportion of communications costs, since variable message signs (VMS) and highway advisory radio (HAR) are heavily dependent on obtaining information from the detection system.
5   Assumes variable message signs and no highway advisory radio.
6   Includes personnel to monitor CCTV and manage VMS/HAR infdrmalbn
7   Includes repair to damaged gates and crash protectbn devices. These costs are uncertain.
8   Moderate estimated to be benefit/coat ratio between 3.0 and 7.0; bw = lower than 3.0; high = higher than 7.0.

Task Activites:

The evaluation of the results will be a primary task of the steering committee. The project team should have conducted their own evaluation prior to meeting with the committee and should have thought through questions the committee may ask. The "reasonableness test" should be applied to ensure that the numbers make sense and can be explained. Illogical numbers can often point to computational or typographical errors. However, there may actually be important, valid relationships underlying numbers that at first appear illogical.

Questions to ask in the evaluation stage include:

- Do one or more of the strategies achieve the previously defined corridor objectives?

- Are the improvements affordable and cost-effective?

- Which improvements are most cost-effective?

- Are there any "fatal flaws" that would make the improvements difficult to implement?

- Are there other improvements or variations that are likely to be more cost-effective, based on the conclusions from the simulated alternatives? (Leads into the next task.)

Task Products:

- Determination by steering committee of direction for remainder of the short-term analysis.

Task 16: Refine Strategies (If Needed)

Task Objective: Make modifications to short-term strategies to Improve performance, and reevaluate, if necessary.

Task Input:

- Evaluation of results in task 15.
- Corridor objectives and operational standards.

Task ActIvItles:

- Determine whether modifications to the strategies evaluated in task 14 could result in significantly improved operation. This typically involves a process of discovering better ways of structuring the strategies through the input of project staff and of other decision- makers. Some strategies may have been determined to be infeasible due to costs, right-of-way requirements, institutional barriers, etc.

- Code modified strategies into the simulation models.

- Perform additional simulations and evaluate results.

Task Products:

- Simulation results for the refined alternatives.

- Presentation package for the steering committee (if needed prior to formulation of recommendations).

Task 17: Make Short-Term Recommendations

Task Objective: Recommend short-term Improvements based on the results of simulations and Input from project staff and decision-makers.

Task Input:

- Refined strategies.
- Results of simulations.
- Input from project staff and decision-makers.

Task Activities:

Recommendations will be based on the effectiveness of the strategies as identified through the simulations (i.e., extent to which they meet geometric and operational standards). balanced with the improvement costs and the sources of funding available to pay those costs. It is often a negotiated process, and cannot simply be subjected to a quantitative analysis. Nevertheless, the simulation results and ensuing evaluation provide the important technical base for making the recommendations.

<u>Task Products</u>:

- List of recommended improvements.

Task 16: Document Results

Task Objective: Prepare a report that clearly describes the analysis process, findings, and recommendations for short-term Improvements.

<u>Task Input</u>:

- Analysis from the simulation activities.
- Other data upon which the recommendation has been based.
- Short-term recommended strategies.

<u>Task Activities</u>:

Figure 19 shows a sample outline for a report to document the results of a simulation modeling activity. The outline is fairly traditional for a transportation engineering evaluation. Depending on whether a long-term evaluation is also conducted, the short-term analysis may be integrated within a larger report.

<u>Task Products</u>:

- Report on short-term improvements.

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Source: New York case study

**Figure 19. Sample report outlIne for reporting results
of short-term operational analysis.**

PHASE III: LONG-TERM ANALYSIS

Task 19: Define Future Regional Condition

Task Objective: Define the transportation facilities expected to be In place, exclusive of the facility changes being evaluated for the defined horizon year.

Task Input:

- Horizon year.
- Regional planning reports and programs.

Task Activities:

One of the primary implications of a long-term analysis is that the changes in traffic volume are likely to be more significant than is possible to predict using simple growth trend analysis. The following would also imply the need and opportunity for a long-term analysis:

- Need for major improvements in the corridor that will take a long period to implement (e.g., addition of a lane that requires major reconstruction).

- Need to examine long-term implications even though the strategy may be implementable in the short term.

A definition of the future regional condition is needed primarily to establish the basis for the traffic forecasts. Ordinarily, the region will have an approved program of fundable transportation improvements, which is used as the basis of most forecasts in the region. The current year for the regional planning horizon is an important input to the selection of the horizon year for the corridor evaluation, particularly where it is expected that forecasts will be required. If different horizon years are used, a more involved forecasting process or interpolation of other available forecasts must be employed.

To define the future regional condition, the following must be considered:

- Assumed existence of new highway facilities, particularly in the area immediately surrounding the corridor being analyzed.

- Number of lanes available on the future roadway network.

- Major transit and travel demand management strategies to be implemented by the horizon year.

- Nature of priority treatments or other strategies aff ecting demand.

Task Products:

- Definition of conditions under which the long-term evaluation is to take place.

Task 20: Obtain Traffic Forecasts

Task Objective: Obtain forecasts from the regional plannlng agency or other appropriate entlty (or conduct them in-house as part of the project).

Task Input:

- Definition of future regional condition (task 19).

- Forecasting activities of the Regional Planning Agency, Department of Transportation, or other appropriate source.

- Procedure for developing hourly and 15-min traffic forecasts from the results of travel demand forecasting efforts.

- Existing traffic counts.

- Validation year fun of the regional traffic forecasting model.

Task Activities:

Developing traffic forecasts for use in freeway simulation models is not a trivial exercise. While daily or peak period forecasts may be adequate for broad-based planning-level corridor evaluation, traffic forecasts for input into a simulation model must be subjected to a higher degree of scrutiny and refinement. Freeway simulation models are highly sensitive to traffic volume, and the lengths of queues can vary dramatically with just small changes in volume.

The output from travel demand forecasting models are usually in the form of daily forecasts, peak period forecasts, and/or peak hour forecasts. Producing reasonable traffic forecasts on a peak hour basis is very difficult. One is doing quite well if the peak hour volume for a validation on a typical freeway is within 15-percent The difference of 15-percent is enough to make large differences in queue lengths and delays in a freeway simulation model. In addition, ramp forecasts typically vary considerably more than 15-percent. This is because the volumes on ramps are lower than volumes on the mainline, and the accuracy of ramp forecasts are highly dependent on the nature of the zone system coded into the network within the vicinity of each interchange. Therefore, it is important to subject the forecasts to a systematic process of refinement, based on accepted procedures.

National Cooperative Highway Research Program (NCHRP) Report 255 entitled "Highway Traffic Data for Urbanized Area Project Planning and Design" prescribes a set of procedures for refining the forecasts generated by travel demand forecasting models. The simulation modeler must either develop a refined set of forecasts acceptable for simulation or ensure that an acceptable set is provided by others. Often, those who are providing the forecasts are not aware of the specific needs of the corridor study and may not give adequate attention to the details of developing an acceptable forecast for simulation purposes. Failure to give adequate attention to this stage could potentially result in an invalid set of conclusions. Producing these refined forecasts requires an understanding of travel demand forecasting, the zone system used within the corridor, and the principles of producing these forecasts.

In essence, traffic refinement involves using the relationship between existing counts and the volumes from the validated traffic model to improve the future estimates. This could involve activities such as balancing traffic volumes on parallel facilities across a screenline, modifying the forecasts by the incremental volume (or ratio of volumes) between the base year counts and validation year modeled volumes, or similar techniques. *NCHRP Report 255* should be consulted for more details. Peak hour to daily ratios and directional factors will need to be applied if forecasts are conducted only on a daily basis.

One simplified method of creating the future volumes may be to compute a percentage growth using daily or peak period numbers and to apply those percentages on a link-by-link or interchange-by-interchange basis. This assumes that peaking characteristics for the future year will stay the same as for the current year. The volume forecasts may also need to be subjected to a balancing process to rectify imbalances in the inbound and outbound volumes.

Another major issue in developing forecasts is the elasticity of demand with respect to available capacity. Adding a lane on a freeway will normally affect demand, and the analyst must define the specific geometric condition for which forecasts are to be prepared . More discussion of this issue is presented in task 21.

Task Products:

- Documented traffic forecasts in spreadsheet form, ready into be input to the model.

Task 21: Simulate Future No-Build Condition

Task Objective: Identify the nature and magnltude of problems anticipated when traffic forecasts are loaded onto the existing system.

Task Input:

- Forecast volumes.
- Validated simulation model.

Task Activities:

The primary work effort leading up to simulating the future no-build condition involves the validation of the simulation model (task 11) and the development of the ramp-by-ramp and time slice-by-time slice forecasts (task 20). Entering the volumes into the model and conducting the run is a relatively simple task. The results are usually quite enlightening and significant. Contours of queuing, speed, and density provide a good overview of the forecast congestion.

Occasionally, particularly in higher growth areas, the congestion created by the simulation will last completely through the simulation period, resulting in residual travel that was not actually simulated. As stated in task 4, the simulation time periods should be selected to prevent this from occurring. This is particularly important if comparisons of vehicle hours of travel are being developed. If residual travel exists (i.e., traffic queues remain on ramps or on the mainline at the end of the simulation period), comparisons of no-build vehicle miles (VMT) and vehicle hour (VHT) with improved conditions will be invalid. If adding additional time slices to the simulation period is impractical (due to lack of data or other reasons), one method of "releasing the queues" is to add one or more simulation periods with zero volumes at the entry points (or a volume of one if the model will not accept a zero). While this creates a slight bias toward better conditions than wouid actually occur, it is more preferable than not fully account for all of the VMT within the simulation period.

One of the complex issues that arises in simulating a future no-build condition is whether the projected demand could actually occur. Often, there will be only one travel demand for use in the simulation activity. In reality, demand will be affected by the available capacity. The capacity limitation in the no-build condition would tend to constrain demand on the freeway, through diversion to other routes and perhaps even through changes to the way in which land develops. For a thorough analysts, forecasts should ideally be prepared to cover each geometric condition (no-build and the various build alternatives) for which demand could change. If these are not available, the analyst should at least state that the forecasts do not account for the effect of changing available capacity. This issue again highlights the importance of using the combined abilities of travel demand models and freeway simulation models.

Task Products:

- MOEs under future no-build conditions.

Task 22: Identify Future Problems and Probable Causes

Task Objective: Identify future geometric and operational problems based on the simulation of the no-build condition, and note probable causes.

Task Input:

- Simulation of future no-build condition.
- Problems/cause check list from chapter 5.

Task Activities:

The process of identifying problems and possible causes will follow a course very similar to that in task 12. However, there will be no base of existing observation upon which to operate (i.e., all the problems will be predicted). Figure 20 shows a typical contour diagram that may result from the simulation of the sample section. The primary inferences that can be made from this figure and associated data is that there will be a major congestion problem in the horizon year and that section 21 appears to be a key bottleneck location. One cannot draw conclusions on the requirement for basic lanes or for the more detailed geometric design features (e.g., interchange spacing, auxiliary lanes, etc.) without further analysis. Many of the future problems upstream and downstream from the bottleneck section are actually hidden by the presence of queuing in the bottleneck section.

The contour diagram is useful to convey the message to the steering committee (and to the public, if appropriate) that " if nothing is done to improve freeway geometries or operation or to reduce demand, this is what is likely to happen.' The queue contour diagram is one of the best visualizations the project team can give of the consequences of inaction. This may be one of the most important points made with the simulation model during the project.

A useful activity to make an initial assessment of the magnitude of the problem is to conduct a "bottleneck elimination analysis: This is an activity in which lanes are added to the simulation network until bottlenecks have been eliminated (i.e., level of service (LOS) E or better). While this may not be the defined operational standard for the freeway system, it provides a quick indication of the approximate levels of geometric improvement necessary to free the system of queues in the horizon year. Although adding the lanes necessary to solve the congestion problem may not be physically or financially feasible, conducting the bottleneck elimination analysis will assist the analyst in understanding the magnitude of the problem and the implications of that problem on designing acceptable solutions. It will also provide an initial simulation-based assessment of the number of lanes needed to solve the congestion problem. This activity should require only one day of effort for the macroscopic models. The longer run times with a microscopic model could require several days. The primary output from each run would be contour diagrams that could be used to quickly evaluate the adequacy of the improvements coded into the previous run.

Speed

```
Time                                          (mi/h 10)                                          Start
Slice   .................        .......... .........  ..  ...  ...   ..   .... ....... ..       Time
 11  | 000000000011111111111111111111111111111111111111111111111111111112222222233333334444455555544411444555555 |   8:45
 10  | 000000000000000000111111111111111111111111111111111111111111111111111222222223333333444445555554441144455566 |   8:30
  9  | 000000000000000000000011111111111111111111111111111111111111111111111122222222333333344444444455544411444555555 |   8:15
  8  | 000000000000000000000011111111111111111111111111111111111111111111111112222222233333334444444445554411444555555 |   8:00
  7  | 0000000000000000001111111111111111111111111111111111111111111111111111122222222333333344444444455544411444555555 |   7:45
  6  | 000000000011110001111111111111111111111111111111111111111111111111111112222222233333334444444455555522444555555 |   7:30
  5  | 1111111111111111111111111111111111111111112222222222221111111111111111112222222233333334444455555555554455566666 |   7:15
  4  | 2222222222222222221111111111111111111111111222222222333444444422111111111112222222233333334444455555555555555555666 |   7:00
  3  | 3333333333333344444422222221112222222222222222222333444444332222222222333333333333333334455544455555555555555666666 |   6:45
  2  | 4444444444444455555555533333333333333333333333334444445555555555555554444444444444444455555555566666655566666666 |   6:30
  1  | 6666666666666666666655555555555555555555555554445555556665555555555555555555555555556666665556666666666666666666 |   6:15
```

```
        |    |  |   |  |  | |    |  |    |  |  | |  |  |  | |  |  |  | |   | |  | |  |  |   | |  |  |
        |    2  3   4  5  6 7    8  9    10 11 1213 14 15 16 1/18 19 2u 21  22 23   2425 26 27 28 2930 31 32
```

Density

```
Time                                       (Veh/Lane-Mi / 10)                                       Start
Slice   ................................................................................            Time
 11  | ••••••••••••••••••••••••••••••••••••••••••••••••999999999••••••••888•••888866655555522333333222222••222111111 |   8:45
 10  | ••••••••••••••••••••••••••••••••••••••••••••99999888888999••••888•••8888777666666333333333222222••222000000 |   8:30
  9  | •••••••••••••••••••••••••••••••••••••••••••999•••••••••888•••99998886666666333333333222333••222111111 |   8:15
  8  | ••••••••••••••••••••••••••••••••••••••••••999999999••••••888•••99997776666663333333332223333992221111 11 |   8:00
  7  | ••••••••••••••••••••••••••••••••••••••••999999•••••••888•••99997766666663333333332222228822211111 |   7:45
  6  | •••••••••••••••••••••••••••••••••••99999999999999•••••••888•••99997766666663333333332222226622211111 |   7:30
  5  | •••••••••••••••••••••••••••999999999888888887777777999••••888•••8888777666666333333333222222322200000 |   7:15
  4  | 99999997776666666••••••••••••••••999999887776663333337•••999•••8888777555555522333333322222222222111111 |   7:00
  3  | 5555555444444333444559999999999999988888877666555333222448885556666666655544444422333333322222222222000000 |   6:45
  2  | 444444333333322222222555555555555554444444444333222222222244333444444444444442222222222211122111111111 |   6:30
  1  | 2222222211122221111111133333222333333333333333333333222222222333222333333332222222221112222222221111111000000 |   6:15
```

```
        |    |  |   |  |  | |    |  |    |  |  | |  |  |  | |  |  |  | |   | |  | |  |  |   | |  |  |
        |    2  3   4  5  6 7    8  9    10 11 1213 14 15 16 1/18 19 2u 21  22 23   2425 26 27 28 2930 31 32
```

1 mi = 1.61 km
1 mi/h = 1.61 km/h

Figure 20. Sample speed and density contours from a future no-build simulation.

<u>Task Products</u>:

- List of problems and possible causes for the future no-build condition.

- Queue wntour diagram showing the probable consequences of doing nothing to improve the site.

- Initial indication of the number of lanes needed to eliminate queues in the horizon year (information only, not necessarily an alternative).

Task 23: Identify Candldate Long-Term Strategies

Task Objective: Identify Improvements appropriate for the corridor over the long term.

Task Input:

- Evaluation of problems and probable causes.
- Resutts of prior simulation runs.
- Any short-term recommendations that were made in task 17.
- List of candidate strategies.
- Definition of corridor objectives in task 2.

Task Activities:

Chapter 4 presented a list of candidate strategies typically considered for long-term improvements. These include major geometric changes such as lane additions, interchange modifications, HOV facilities, etc.

The normal process for identifying candidate long-term strategies is the identification of those strategies by project staff, and a presentation to the project steering committee, who will recommend strategies for actual evaluation. The process can range from highly formal to highly informal. However, it is important to relate these decisions back to the definition of corridor objectives in task 2.

The steering committee will identify the strategies generically. It will be up to the project staff to translate the exact characteristics of the strategy into the simulation model. For example, 'add one lane' is a generic strategy that would need to be fined-tuned for simulation purposes, perhaps adding an auxiliary lane, or varying the number of lanes as appropriate to optimize operation within available right-of-way.

A question that immediately follows from the identification of candidate long-term strategies is "Will the traffic demand change significantly with the candidate improvements?"

If the answer to this question is yes, it may be determined by the project staff that additional forecasts will be required. For example, a wmmon occurrence with a major lane addition is that the added capacity will draw additional trips onto the freeway. Failure to account for this phenomenon could mean that the traffic forecasts obtained in task 20 actually under-represent the volumes that might be expected to occur on the freeway. This is an important technical and policy decision that must be made by those involved with a project It may be particularly important to consider the additional forecast if there is a significant environmental component (e.g., air quality analysis) to the project or if mods shifts are involved. Depending on the context of the study, critics could accuse the analysis of being incomplete. It is important to understand that the simulation models will not, by themselves, take into consideration the effect on demand of capacity modifications in the corridor. A travel demand forecasting model must be employed if the effect on demand is to be taken into account.

Task Products:

- Listing of specific long-term strategies to be evaluated.

Task 24: Obtain Modified Forecasts

Task Objective: Obtaln or conduct addltlonal future year forecasts that account for changes In demand brought about by the project alternatives.

Task Input:

- Prior forecasts.
- Definition of alternatives.
- Regional or corridor travel demand forecasting model.
- Traffic refinement procedures.

Task Activities:

It is assumed that the forecast will either be conducted by the regional agency or will be conducted by project staff. The specific alternatives will need to be coded into the model and forecasts prepared for each scenario. An important factor in conducting the forecasts is a zone system in the corridor that is appropriate for addressing the ramp-by-ramp volume needs. Conducting additional corridor-specific forecasts usually requires additional travel demand model development efforts, including the addition of links and zones in the immediate area surrounding the freeway. As thii activity can require additional time and cost, it is important to anticipate the need for the additional model development long before the forecasts are needed. Usually, it can be anticipated at the beginning of the project and written

into the scope of work. The travel demand model development work can proceed in conjunction with the freeway simulation work, even if the specific freeway alternatives are not known. As with any forecast from a travel demand model, the volumes will need to undergo the refinement process, as referred to earlier in task 20.

Task Products:

- Forecasts for each ramp and at the beginning and end of the simulated section by 15-min time period. A forecast should be conducted for each major geometric alternative.

Task 25: Simulate Long-Term Strategies

Task Objective: Use the simulation models and associated analytical tools to produce the measures of effectiveness that will be used to evaluate the relative benefits and required design features of the long-term strategies.

Task Input:

- Candidate long-term strategies.
- Validated simulation models.
- List of MOE's to be produced.

Task Activities:

The process of simulating the long-term strategies follows an identical process as for the short-term strategies, and the guidelines specified in task 14 also apply here. Chapter 4 should be referenced for guidance on a basic simulation approach for each type of strategy. Figure 21 shows a method of illustrating differences between alternatives using the queue contour diagrams.

Task Products:

- A comparison of MOE's among the alternatives. Charts and tables should be prepared that clearly present the information to the steering committee for review.

- A brief memorandum may be needed transmitting and interpreting the information. However, handouts given to members at the meeting may be appropriate, depending on the level of formality and the timing of the meeting.

1989

2010 No-Build

2010 with Lane Addition

2010 with Lane Addition
and Ramp Metering
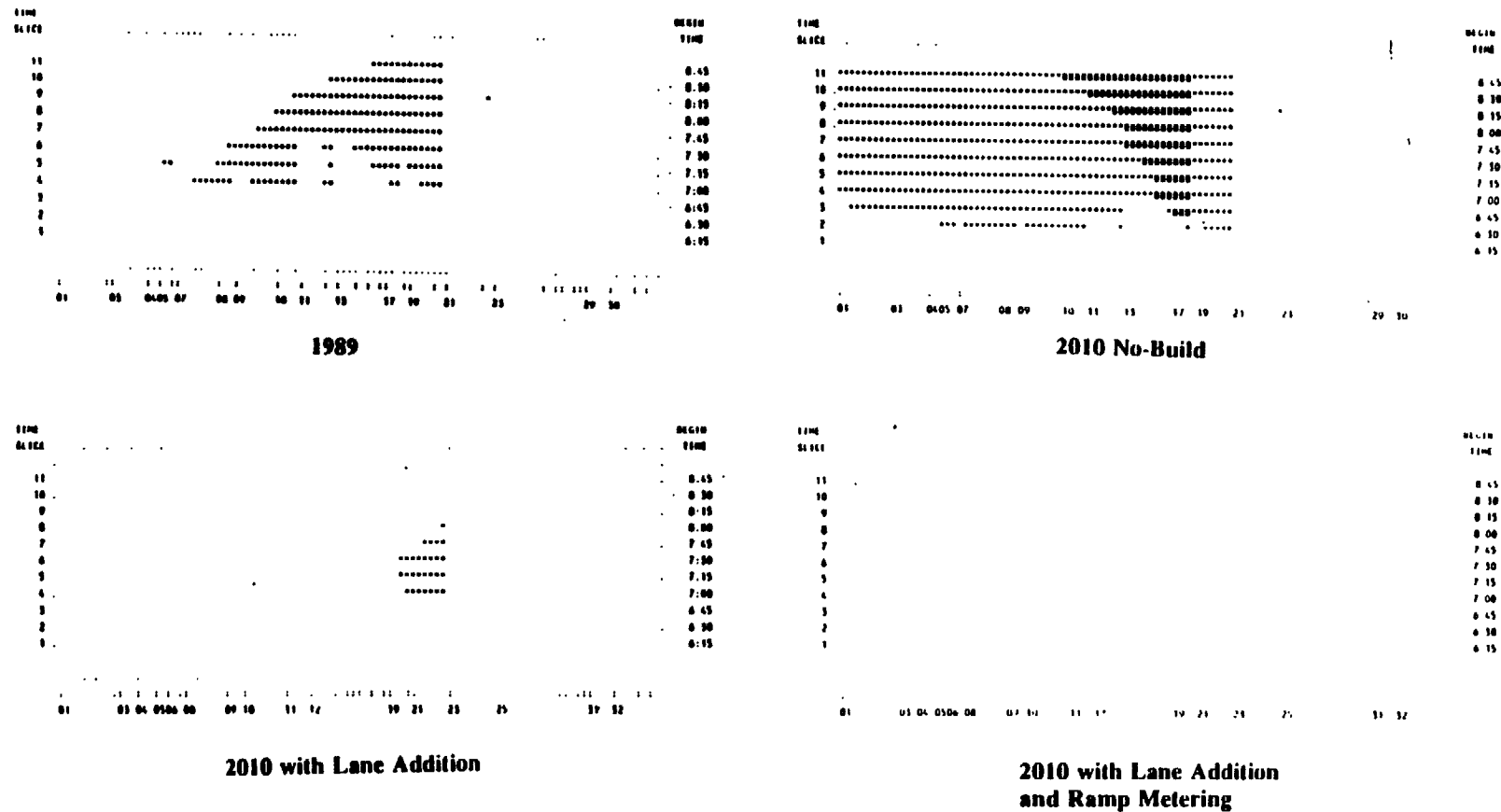
Figure 21. Sample comparison of queue contours.

Task 26: Evaluate Results

Task Objective: Determine whether the simulation indicates that the Improvements will achieve operational objectives for the corridor, and define the optimum alternatlve.

Task Input:

- MOE's produced through the modeling process.
- Corridor operational objectives.
- Decision-making structure for agency staff and elected officials.

Task Actlvltles:

The evaluation of the results will be a primary task of the steering committee. The project team should have conducted their own evaluation prior to meeting with the committee and should have thought through questions the committee may ask. The reasonableness test" should be applied to ensure that the numbers make sense and can be explained. Illogical numbers can often point to computational or typographical errors. However, there may actually be important, valid relationships underlying numbers that at first appear illogical.

Questions to ask in the evaluation stage include:

- Do one or more of the strategies achieve the previously defined corridor objectives?

- Are the improvements affordable and cost-effective?

- Which improvements are most cost-effective?

- Are there any 'fatal flaws' that would make the improvements difficult to implement?

- Are there other improvements or variations that are likely to be more cost-effective, based on the conclusions from the simulated alternatives? (Leads into the next task)

Task Products:

- Determination by steering committee of direction for remainder of the short-term analysis.

Task 27: Refine Strategies (If Needed)

Task Objective: Make modifications to short-term strategies to improve performance, and-reevaluate, if necessary.

Task Input:

- Evaluation of results in task 26.
- Corridor objectives and operational standards.

Task Activities:

- Determine whether modifications to the strategies evaluated in task 25 could result in significantly improved operation. This typically involves a process of discovering better ways of structuring the strategies through the input of project staff and of other decision- makers. Some strategies may have been determined to be infeasible due to costs, right-of-way requirements, institutional barriers, etc.

- Code modified strategies into the simulation models.

- Perform additional simulations and evaluate results.

Task Products:

- Simulation results for the refined alternatives.

- Presentation package for the steering committee (if needed prior to formulation of recommendations).

Task 28: Make Long-Term Recommendations

Task Objective: Recommend long-term Improvements based on results of simulations and Input from project staff and decision-makers.

Task Input:

- Refined strategies.
- Results of simulations.
- Input from project staff and decision-makers.

Task Activities:

Recommendations will be based on the effectiveness of the strategies as identified through the simulations (i.e., extent to which they meet geometric and operational standards), balanced with the improvement costs and the sources of funding available to pay those costs. It is often a negotiated process, and cannot simply be subjected to a quantitative analysis. Nevertheless, the simulation results and ensuing evaluation provide the important technical base for making the recommendations.

Task Products:

- List of recommended long-ten improvements.

Task Activities:

Same process as used in the evaluation of short-term strategies.

Task Products:

- Determination of which alternatives achieve the operational objectives and which is the preferred alternative.

- Identification of modified alternatives to be simulated and evaluated.

Task 29: Document Results

Task Objective: Prepare a report that clearly describes the analysis process, findings, and recommendations for long-term improvements.

Task Input:

- Analysis from the simulation activiies.
- Other data upon which the recommendation has been based.
- Long-term recommended strategies.

Task Activities:

      The documentation of long-term strategies will follow essentially the same process and similar report outline to the documentation of short-term strategies.   Following the preparation of this report, a final traffic report can be prepared.   If the earlier reports are prepared with their inclusion into the final report in view, the final report can be a compilation of the earlier reports, with modifications reflecting the comments received and lessons learned along the way. An executive summary, concisely discussing the key results and recommendations, is essential to making the report useful to decision-makers and the public. Figure 22 illustrates a sample outline that would be typical of an analysis report for long-range analysis.

Task Products:

- Report on results of the analysis of long-term strategies.

- Final report, incorporating the findings of the other reports prepared at intermediate stages in the project.

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Figure 22. Sample report outllne for long-term analysis report.

CHAPTER 7. SUMMARY OF CASE STUDIES

The conclusions regarding the four models discussed in the preceding chapters of this report were based in part on five case studies. Each case study involved the application of two or more of the models to a real world situation. The studies were designed to provide a common base of experience for assessing each model, its ease of application, and areas where it might be improved. They were also designed to illustrate how the models might be used to help assess specific improvement schemes at each location.

Each study had a particular focus and was designed to test specific features of the models involved. The five study locations and their major points of emphasis were:

- **I-5 In Seattle, Washington** - Involved the evaluation of truck-climbing lanes, HOV lanes, ramp-metering, truck restrictions, and weaving restrictions.

- **The George Washington Bridge/Cross Bronx Expressway In New York and New Jersey** - Emphasized the effects of major and minor freeway incidents on traffic flow under high-volume conditions.

- **I-94 In Milwaukee, Wisconsin** - Focused on major geometric modifications to the existing freeway and the implementation of HOV lanes and ramp metering.

- **MO and MI In Columbus, Ohio** - Involved the analysis of complex weaving sections and major changes in freeway geometry.

- **I-494 In Minneapolis, Minnesota** - Focused on major changes in geometry with and without HOV lanes and ramp metering.

Each of the five case studies is described in detail in a series of three reports:

- **Evaluation Plan** - Describes the study location and existing site conditions, the focus of the analysis, potential site improvements, proposed model applications, input data requirements, and a work plan for conducting of the study.

- **Model Calibration Report** - Describes the procedures used to calibrate each of the models to match existing conditions, together with the results of the calibration.

- **Alternative Analysis Report** - Describes the application of the models to evaluate several alternative improvement programs, including selection of a recommended alternative and an assessment of the adequacy of the models as evaluation tools.

A complete list of these reports is given in figure 23. This chapter briefly summarizes each case study. Copies of the full case study reports are available from FHWA.

Case Study #1: **Seattle, Washington**	**(I-5 southbound between State Route 900 and State Route 18)**	**I.1** *Case Study Evaluation Plan*, December 1988 **I.2** *Model Calibration Report* October 1989 **I.3** *Alternatives Analysis Report*, April 1992
Case Study #2: **New York/New Jersey**	**(George Washington Bridge and Cross Bronx Expressway eastbound between G. W. Bridge Toll Plaza and White Plains Road)**	**II.1** *Case Study Evaluation Plan*, January 1989 **II.2** *Model Calibration Report*, October 1989 **II.3** *Incident Management Alternatives Analysis Report* December 1989
Case Study #3: **Milwaukee, Wisconsin**	**(I-94 eastbound between U.S. 45 and I-43)**	**III.1** *Case Study Evaluation Plan*, January 1989 **III.2** *Model Calibration Report,* December 1989 **III.3** *Alternatives Analvsis Report,* April 1992
Case Study #4: **Columbus, Ohio**	**(I-71 northbound between I-70 and I-670)**	**IV.1** *Case Study Evaluation Plan*, January 1989 **IV.2** *Model Calibration Report,* December 1989 **IV.3** *Alternatives Analysis Report,* April 1992
Case Study #5: **Minneapolis, Minnesota**	**(1494 eastbound between Prairie Center Drive and TH5)**	**V.I** *Case Study Evaluation Plan*, January 1989 **V.2** *Model Calibration Report,* August 1990 **V.3** *Alternatives Analysis Report,* April 1992

Figure 23. Detailed case study reports

CASE STUDY #1: SEATTLE, WASHINGTON

I-5 (Southbound) Between State Route 900 and State Route 18

Study **Location:**

The first case study focused on a 15-mi section of I-5 (southbound), south of downtown Seattle (see figure 24).

The southbound freeway is four lanes wide, with extended lengths of 2-percent to 3-percent upgrade, and both left- and right-hand entrance and exit ramps. Figure 25 illustrates the geometry involved.

Peak hour flows at the time of the study were roughly 6,500 vehicles per hour at the start of the study section, increasing to around 9,000 v/h at critical merge points, and including approximately 8-percent truck traffic. Traffic is projected to grow by roughly 1 P-percent by the year 2010.

The section experiences significant congestion in the evening peak period, with traffic operations normally being at level of service E or F for several miles.

There are extensive bus and carpool/vanpool services in the corridor. The freeway section studied, however, did not include any HOV facilities.

Application of Models:

The HCS software and all three models (FREQ, FREFLO, and FRESIM) were used in the case study.

The HCS procedures were used to estimate capacity by subsection throughout the 15 mi (242 km) study section. The macroscopic FREQ and FREFLO models were used to simulate the entire study section for a 3-h period, spanning the start and end of the PM peak. The FRESIM model was used to examine a shorter section in detail, where serious operational problems occurred due to complex weaving and truck operations on the long upgrade. The FRESIM simulation covered the same 3-h period. Figure 25 shows the section invoked in the FRESIM analyses.

Data on geometry, traffic controls, traffic volumes, and travel times were provided by the Washington State DOT (WSDOT). Volume data were based on 15-min counts conducted in 1988 for each ramp, plus selected mainline locations. Travel time data were based on a limited sample of moving car runs also conducted in 1988. Future traffic demand was based on forecasts for the year 2010, for the mainline entry point, and each ramp supplied by WSDOT.
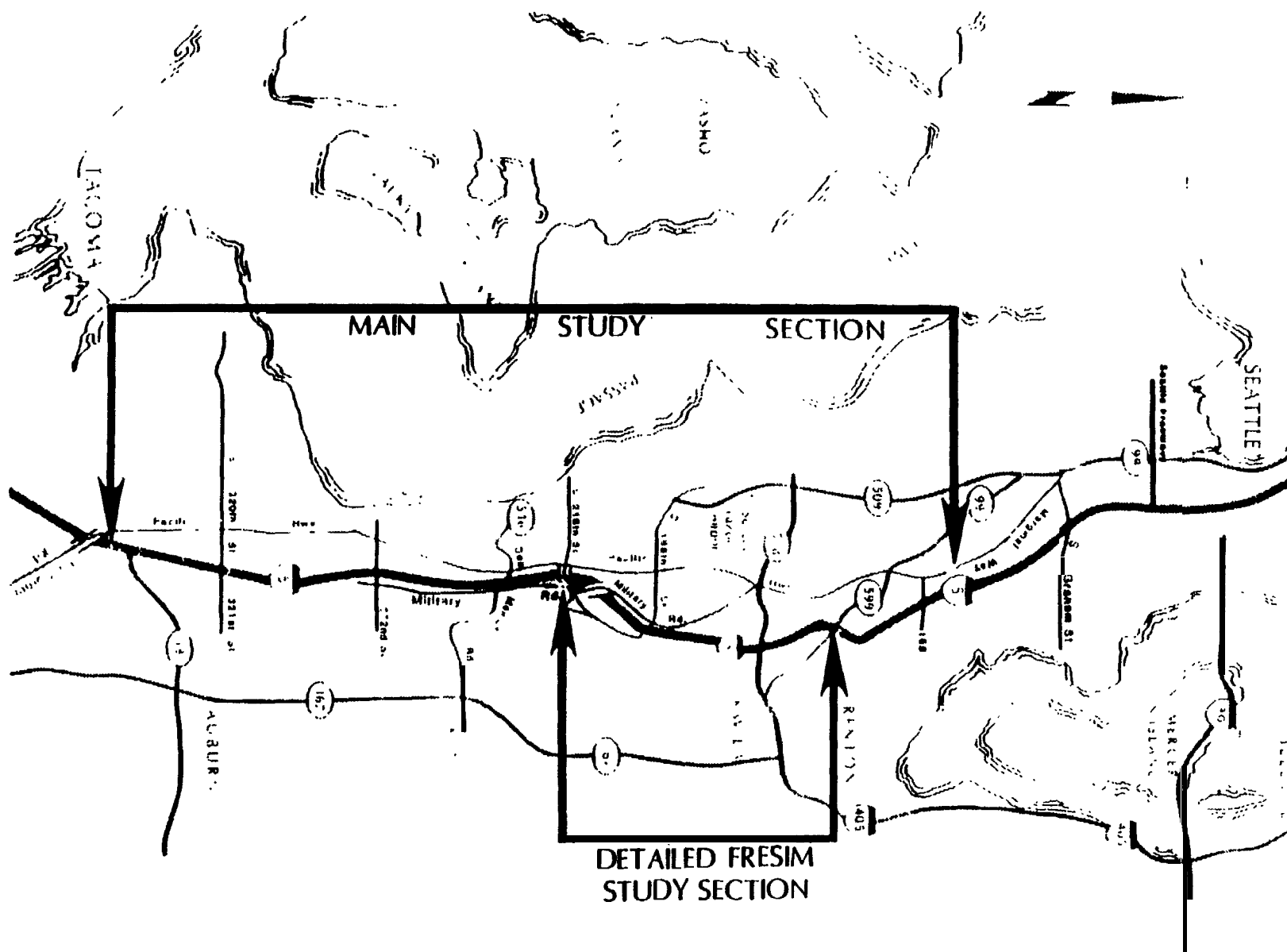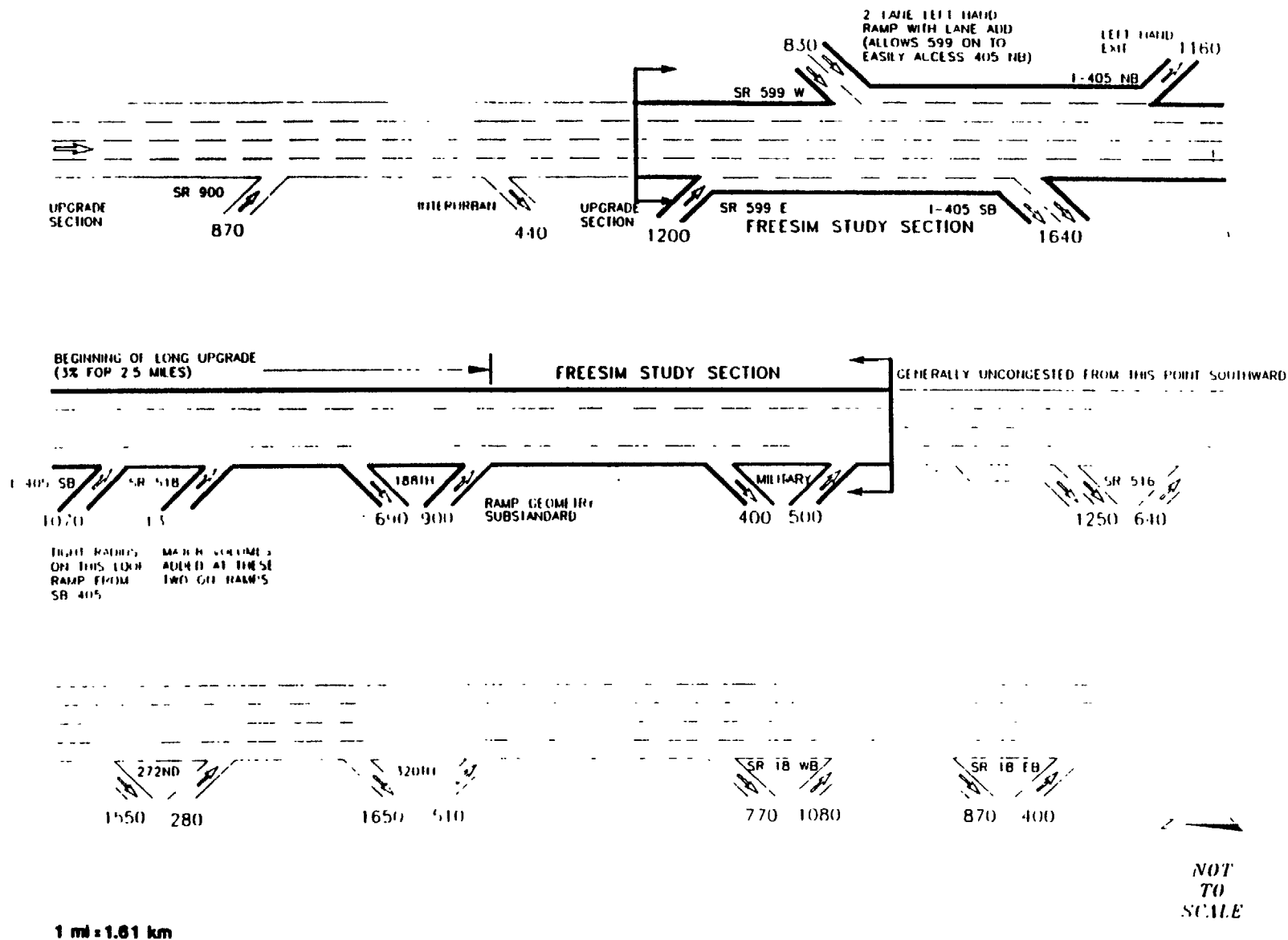
Figure 24. Location of I-5: site in Seattle.

2 LANE LEFT HAND RAMP WITH LANE ADD (ALLOWS 599 ON TO EASILY ACCESS 405 NB)

830

LEFT HAND EXIT 1160

I-405 NB

SR 599 W

SR 599 E   I-405 SB

UPGRADE SECTION

SR 900

870

INTERURBAN

440

UPGRADE SECTION

1200   FREESIM STUDY SECTION

1640

BEGINNING OF LONG UPGRADE (3% FOR 2.5 MILES)

FREESIM STUDY SECTION

GENERALLY UNCONGESTED FROM THIS POINT SOUTHWARD

I-405 SB   SR 518

1070   15

188TH

640   900

RAMP GEOMETRY SUBSTANDARD

MILITARY

400   500

SR 516

1250   640

TIGHT RADIUS ON THIS LOOP RAMP FROM SB 405

MATCH VOLUMES ADDED AT THESE TWO ON RAMPS

272ND

1550   280

320TH

1650   510

SR 18 WB

770   1080

SR 18 EB

870   400

NOT TO SCALE

1 mi = 1.61 km

Figure 25. Seattle I-5: existing lane configuration 1988 p.m. peak hour ramp volumes.

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Model Calibration:

For both FREQ and FREFLO, a critical input to the modeling process is freeway lane capacity by section.

For both models, an initial set of base-case runs (i.e., for 1988 conditions) were made using the normally recommended capacity value of 2,000 pcplph, as modified by truck-related and weaving adjustments. Use of this value, however, produced model results that indicated a substantially higher level of congested traffic than was observed in the field, expressed in . terms of speed and density plots (see below). Further investigation of the volume data indicated that existing volumes were well in excess of the established 2,000 pcplph guideline, and that on numerous occasions volumes of 2,200 pcplph were observed with speeds of 40 mi/h (64.4 km/h) or higher.

Additional model runs were made with varying lane capacities, leading ultimately to the selection of 2,100 pcplph as a lane capacity on level terrain based on matching simulated volumes to actual, observed volumes. A similar adjustment was also made in terms of the HCS truck factors.

Figure 28 compares the speed profiles generated from the calibrated FREQ and FREFLO models with the equivalent profile obtained from actual travel-time runs for the period 4:00 to 4:15 PM. The patterns were similar but by no means identical. Both models indicated the presence of a bottleneck in the vicinity of the I-405 interchange, with FREQ appearing to represent downstream recovery more effectively than FREFLO. This was confirmed by the speed contour plots illustrated in figure 27, which suggest that FREFLO also tended to exaggerate the severity, extent, and duration of congestion compared to FREQ. Unfortunately, no further field observations of actual speeds/travel times were available to permit a comparison of the model to field data for time periods other than 4:00 to 4:15 PM.

In the case of FRESIM, the model may be calibrated by varying a number of parameters reflecting driver behavior. In the absence of evidence to the contrary, the model employed standard default values. These were utilized in this case. The resultant volumes generated by FRESIM matched the field observations satisfactorily. The equivalent speed profile for the period 4:00 to 4:15 PM shown in figure 26, covering the short section to which FRESIM was applied. Again, the model output followed the general form of the field observations, but in this case appeared to underestimate field conditions somewhat.

Figure 28 illustrates the FRESIM speed contour plot for the subsection simulated. While direct comparisons to the output generated by the other models was not valid due to the different lengths of freeway analyzed, the plot generally conformed more closely to the FREQ results than to those generated for FREFLO.

Evaluation of Existing Conditions and Development of Alternatives:

Together with field observations of actual traffic conditions, the runs of the calibrated models were used as a stating point for the analysis of desirable improvements.
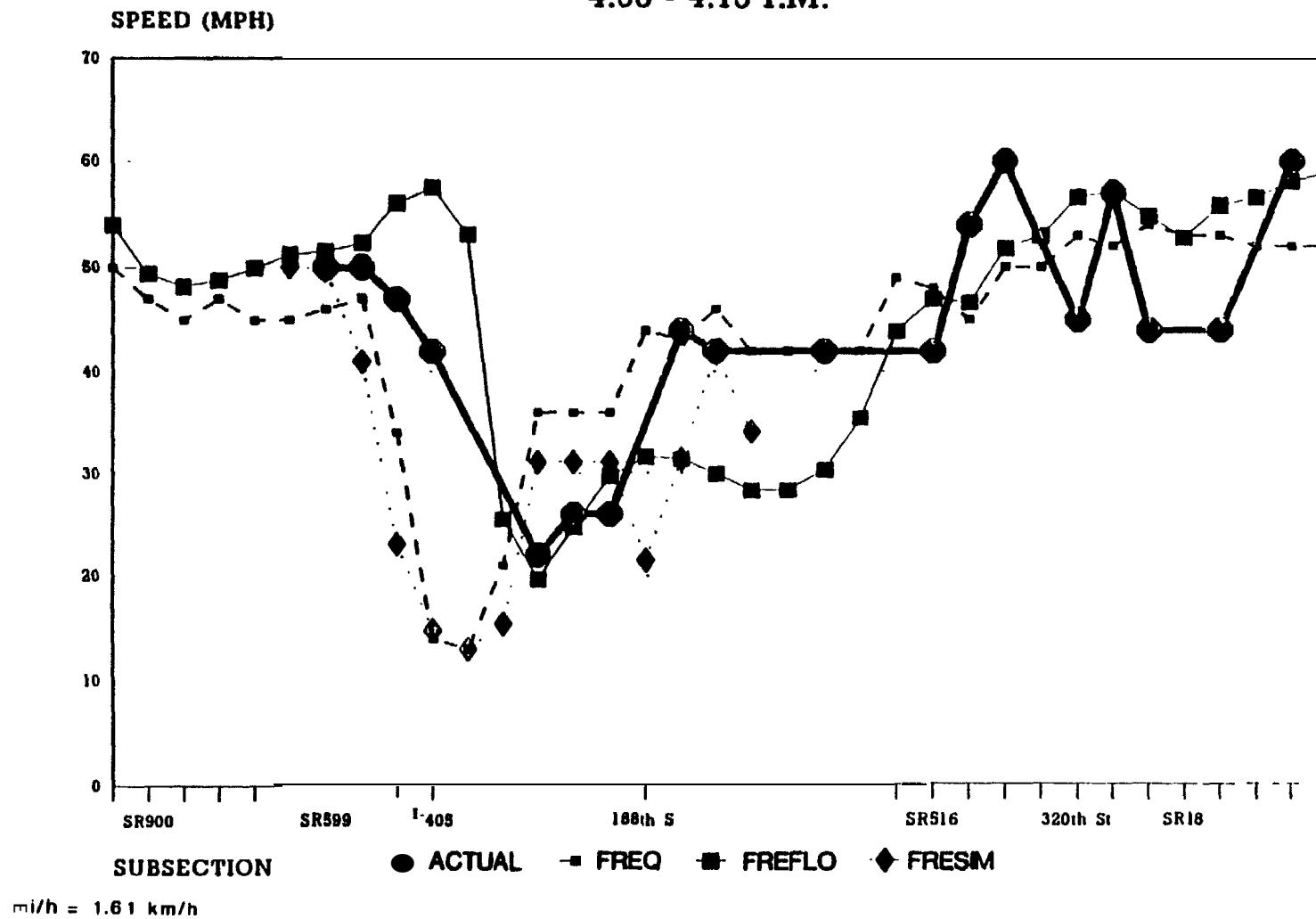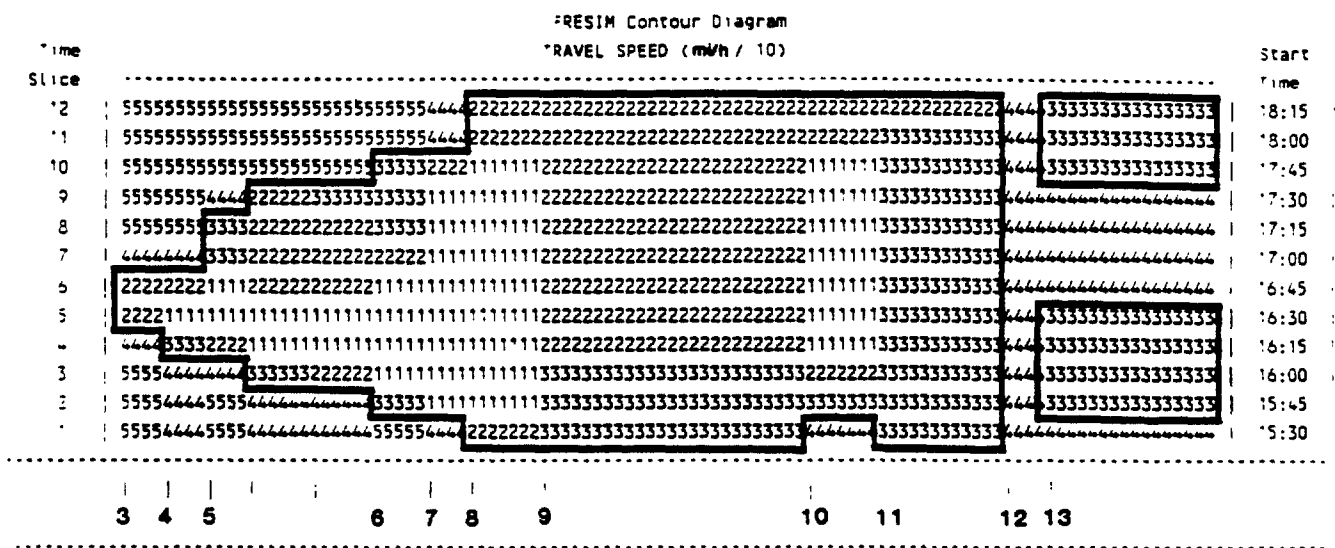
I-5 SEATTLE (1988)
4:00 - 4:15 P.M.

SPEED (MPH)

SUBSECTION   ● ACTUAL   ─■ FREQ   ▩ FREFLO   ◆ FRESIM

mi/h = 1.61 km/h

Figure 26. Seattle I-5: site speed profiles for existing conditions.

```
TIME                                        (mi/h 10)                                              BEGIN
SLICE  ..................................................................................................  TIME

  12  .5555555555555555533222333333333333344444444444444444445544444444444444444455555555555555555555.  ·  18:15
  11  .55555555555555533311111133333333333344444444444444444444444455555555555555555555555555555555555.  ·  18:00
  10  .5555555555522111111222333333333333344444444444444444444444455555555555555555555555555555555555.  ·  17:45
   9  .5444444444411111112223333333333334444444444444444444444455555555555555555555555555555555555555.  ·  17:30
   8  .444444444441111111222333333333333344444444444444444444444455555555555555555555555555555555555555.  ·  17:15
   7  .54444444432111111122233333333333334444444444444444444444455555555555555555555555555555555555555.  ·  17:00
   6  .4444444432111111122233333333333334444444444444444444444455555555555555555555555555555555555555.  ·  16:45
   5  .54444444441111111222333333333333344444444444444444444455544444444444444455555555555555555555.  ·  16:30
   4  .544444444441111122233333333333334444444444444444444444444555555555555555555555555555555555555.  ·  16:15
   3  .44444444444433111122233333333333344444444444444444444444554444444444444445555555555555555555.  ·  16:00
   2  .54444444444445544222233333333333334444444433333333344444445555555555555555555555555555555555.  ·  15:45
   1  .54444444444455555554443333333333334444444444444445544444444444555555555555555555555555555555.  ·  15:30

       ::  :  :::::  :  : ::  :::       : :   ::    :::  : : :            : :               : :     :::::  :
       02 03    0809   12   15           17  19    22   25               27               29

                                           FREQ
```

```
Time                                        (mi/h 10)                                              Start
Slice  .................................................................................................  Time
  12  | 0011111111111111110000000011111111111222221112222222222222233444444444444555555555555555555555555555555555555  |  18:15
  11  | 11111111111111111111110000001111111111122222111222222222222223444444444444555555555555555555555555555555555555  |  18:00
  10  | 0011111111111111110000000011111111122222222111221112222222223444444444444555555555555555555555555555555555555  |  17:45
   9  | 0000011111110001100000000111111111222222221112222222222222223444444444444555555555555555555555555555555555555  |  17:30
   8  | 1111111111111111111111111111111111112222222222222222222222223444444444444555555555555555555555555555555555555  |  17:15
   7  | 0011111111110001100000000111111111222222222222222222222222223444444444444555555555555555555555555555555555555  |  17:00
   6  | 0000000000000000000000001111111112222222222222222222222222223444444444444555555555555555555555555555555555555  |  16:45
   5  | 5544433222111111100000000111111111222222222222222222222222223444444444444555555555555555555555555555555555555  |  16:30
   4  | 55555555555555555533111111111111122333333333333222222222222223444444444444555555555555555555555555555555555555  |  16:15
   3  | 55444444444455555555555555555552211122222223333322222223333333444444444444555555555555555555555555555555555555  |  16:00
   2  | 55555555555555555555555555555555555533333444444443333333333333344455555555555555555555555555555555555555555555  |  15:45
   1  | 55555555555555555555555555555555544444444444444444444444455555555555555555555555555555555555555555555555555555  |  15:30

       I I  I I  I I  I I I  I I  I I  I I   I  I I  I  I I I  I I  I I  I  I  I  I   I  I I   I I I  I I I
       1 2  3 4  5 6  7 8 9  1011 1213 1415  16 1718 19 2021 2223 2425  26  2728  29    3031   32 3334 3536 37

                                           FREFLO
```

1 mi/h = 1.61 km/h

Figure 27. FREQ and FREFLO speed contour diagrams for 1988 p.m. peak period, Seattle I-5: existing conditions.

```
                                    FRESIM Contour Diagram
 Time                               TRAVEL SPEED (mi/h / 10)                              Start
Slice   ..........................................................................        Time
  12  | 555555555555555555555555555555544422222222222222222222222222222222222222222222222244433333333333333333 |  18:15
  11  | 555555555555555555555555555555544422222222222222222222222222222222222222333333333333444333333333333333  |  18:00
  10  | 55555555555555555555555555555333332222111111122222222222222222222222222211111133333333333333444333333333333333  |  17:45
   9  | 555555554442222223333333333331111111111112222222222222222222222222221111111133333333333344444444444444444  |  17:30
   8  | 555555533332222222222223333311111111111122222222222222222222222221111111133333333333444444444444444444  |  17:15
   7  | 4444444333322222222222222222211111111111122222222222222222222222221111111133333333333444444444444444444  |  17:00
   6  | 2222222211112222222222222111111111111111111112222222222222222222222221111111333333333334444444444444444444  |  16:45
   5  | 2222111111111111111111111111111111111111112222222222222222222222221111111133333333333444333333333333333  |  16:30
   4  | 4444333322221111111111111111111111111111111122222222222222222222222221111111133333333333444333333333333333  |  16:15
   3  | 5555444444433333322222211111111111111111111333333333333333333333332222222233333333333444333333333333333  |  16:00
   2  | 5555444455554444444433333111111111111333333333333333333333333333333333333344433333333333  |  15:45
   1  | 5555444455554444444444455555444222222223333333333333333333333333444444333333333  |  15:30
        ..........................................................................

         |  |  |   |    ;     |  |   '          ;        '  '
         3  4  5          6  7  8  9           10  11       12 13
        ..........................................................................
```

Run A.   Existing Conditions

1 mi/h   1.61 km/h

Figure 28. Seattle I-5: (no-build condition) FRESIM speed contour diagram.

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The contour plots of speed and density for existing conditions generated by both FREQ and FREFLO were used to analyze the buildup and dissipation of current congestion. In addition, runs were made of each model for future traffic conditions. As might be expected, these latter runs indicated a significant deterioration in operations. The results of these analyses were supplemented by a detailed analysis of lane requirements and desirable lane balance, based on the procedures specified in the *Highway Capacity Manual.* This information was then combined with prior assessments of the desirable improvements made by State and local agencies to create a set of potential improvement schemes.

The major operational problems identified as a result of this analysis focused on serious congestion in the vicinity of the I-405 interchange and for approximately 4-mi downstream of that location, due to:

- Heavy and complex weaving in the vicinity of the left-hand on- and off-ramps (see figure 25).

- Slow moving truck traffic on the sustained upgrade.

- Extremely heavy peak-period demand on both the mainline and selected on-ramps.

Four major improvement alternatives were identified as possible means of addressing these problems:

- Metering entrance ramp traffic.

- Adding an additional, mainline lane.

- Restricting all truck traffic to the right-hand lane.

- Prohibiting certain weaving movements - (e.g., prohibiting traffic entering via the SR 599W left-hand on-ramp from exiting via the right-hand off-ramp to I-405 SB approximately 1 -m downstream.

In addition, a further option was identified that converted the added lane to an HOV facility.

Evaluation of Alternatives:

The addition of an extra lane, ramp metering, and HOV alternatives were tested using FREQ and FREFLO for the entire 15-mi (24.2 km) study section. Neither of those models had the ability to restrict truck traffic or prohibit turning movements.

FRESIM was used to examine each of the options tested with the other two models, except that involving the HOV facility (FRESIM does not have the ability to model HOV operations directly) for the most congested 5-mi (8 km) section of freeway.

Ramp metering rates were computed using FREQ's internal optimization process. The same rates were used in FREFLO and as a basis for defining fixed clock-time metering rates for FRESIM.

The results of these analyses are discussed in detail in the *Seattle Alternative Analysis Report* (report I.3 in figure 24).

The FREQ and FREFLO analyses are summarized in figure 29. Both models indicated that the most desirable alternative was that based on adding a lane for general traffic use (i.e., without designation of an HOV lane). Average speeds were highest for this case, and both vehicle miles and person miles of travel were close to the maximum numbers generated for any alternative.

Introduction of ramp metering for the no-build Option improved operations, but not to the extent associated with the addition of a further lane. It resulted in unacceptably long queues at several key entrance ramps. Introduction of an HOV facility tended to lower overall speed, but increased passenger miles of travel.

In interpreting these results, three cautions should be borne in mind:

- In most of the runs a 'closed system' was not achieved – that is, congestion appeared to extend beyond the boundaries of the study section and time-period analyzed. The result was that delay may therefore be underestimated.

- The statistics in figure 29 did not take into account the adjacent arterial street network, again resulting in a possible underestimate of delay.

- The statistics for the HOV alternatives reflected the average of the priority and nonpriority lanes.

The results of the detailed FRESIM analysis for the shorter, more congested subsection are summarized in figure 30.

In this case, the best long-range solution was again clearly the addition of another lane, with smaller additional Improvements being associated with the restriction of truck traffic to the right-hand lane and restricting weaving between the left-hand entrance from SR 599 and the right-hand exit to I-405.

Under existing traffic volumes, institution of ramp metering coupled with the restriction of truck traffic to the right-hand lane produced a marked improvement in operations. These measures alone, however, with no lane addition, did not produce acceptable operations under future traffic demand.

SEATTLE I-5 ALTERNATIVE ANALYSIS

3:30 – 6:30 PM

			AVE. FWY SPEED mi/h	MIN. SPEED mi/h	FWY.TRAVEL TIME VEH.HRS.	ON-RAMP DELAYS VEH.HRS	TOT.TRAVEL TIME VEH.HRS	DISTANCE TRAVELLED VEH.MI	TRAVELLED PASS.MI	OVERALL AVE. SPEED mi/h	MAX. V/C	FUEL USED GAL.	CO EMISS. KG.
YEAR 1988													
BASE CONDITION		FREQ	40.8	12.0	0,136	376	8,512	332,358	473,599	39.0	1.00	23,276	7,070
		FREFLO	29.6	0.0	10,368	n/a	n/a	306,919	392,550	n/a	n/a	n/a	n/a
YEAR 2010													
NOBUILD	W/O TSM	FREQ	35.9	12.0	9,449	4.142	13,591	338,983	403,585	24.9	1.00	26,053	13.422
		FREFLO	26.2	6.7	11,558	n/a	n/a	302,197	387,114	n/a	n/a	n/a	n/a
	U/METERING	FREQ	48.1	43.0	6,767	5,383	12,150	325,275	447,106	26.8	0.93	25,283	12,836
		FREFLO	50.6	32.7	6,230	n/a	n/a	314,986	402,237	n/a	n/a	n/a	n/a
ONE LANE ADDITION	W/O ISM	FREQ	50.4	38.0	7,171	6	7,177	361,076	515,519	SD.3	0.97	25,763	7,327
		FREFLO	55.0	49.3	6,229	n/a	n/a	353,513	451,436	n/a	n/a	n/a	n/a
	* u/HOV	FREQ	47.1	15.0	7,810	1	7,811	368,045	532,535	47.1	1.00	27,386	7,606
		FREFLO	34.7	10.0	10,293	n/a	n/a	356,748	486,274	n/a	n/a	n/a	n/a
HOV ALTERNATIVE	*	FREQ	35.3	12.0	9,734	1,509	11,243	343,748	501,327	30.6	1.00	26,016	10,449
		FREFLO	27.3	8.1	11,712	n/a	n/a	319,222	435,199	n/a	n/a	n/a	n/a

1 mi/h = 1.61 km/h

* Note: The HOV alternative statistics represent the combined performance of both the priority-lane and the non priority lanes.

Figure 29. Seattle I-5: alternative analysis summary of freeway performance.

Alternative	Total VMT (miles)	Total VHT (hours)	Average Speed (mi/h)	Delay Time (min/veh-mi)
Base Case				
Existing Traffic	123,411	4,532.9	17.2	1.08
Existing Traffic with **TSM Measure**[1]	109,840	2,338.6	46.9	0.16
Future Traffic	N/A2	N/A	N/A	N/A
Future Traffic With TSM Measure[1]	N/A2	N/A	N/A	N/A
Lane Addition With Future Traffic				
No Restriction on Mainline	144,989	3,552.7	40.8	0.36
Restricting SR 599 to I-405 movement	146,496	3,721.0	39.4	0.41
Lane Addition With Truck Restriction Using Future Traffic				
No Restriction on Mainline	144,783	3,524.4	41.1	0.35
No Restriction on Mainline	146,390	3,705.8	39.5	0.41

1 m = 1.61 km
1 mi/h= 1.61 km/h

[1] TSM Measures are: fixed rate clock-time metering at selected ramps and restricting trucks to extreme right lane.
[2] Simulation run aborted due to excessive demand and queue along the mainline and certain ramps.

Figure 30. Seattle I-5: FRESIM analyses, effectiveness of various alternatives.

Lessons Learned:

Several important lessons were learned from the analyses, regarding both the alternatives tested, the process of analysis, and the relative strengths and weaknesses of the various models. These are highlighted below:

Recommended Improvement: All of the model analyses yielded essentially the same conclusion. Under the projected 12-percent increase in traffic, no measure other than the addition of a substantial increase in capacity through construction of a fifth mainline lane would result in a satisfactory level of operation. Other measures, including ramp-metering, truck and weaving restrictions, etc. would help improve operations temporarily. They would not, however, address the long-term problem. Implementation of an HOV lane, provides for improved bus and car/Vanpool operation, but at the expense of operations in the remaining mixed traffic lanes. The primary uncertainty, which is not addressed by freeway simulation is how the provision of an HOV lane may influence traffic demand (i.e. creation of new carpools and shifts from auto to transit). A travel demand modeling effort would be needed to fully address these questions.

The Analysis Process: The analysis process was constrained in a number of respects due to the availability of data, and the limitations of the models employed. Four points should be made here:

- The simulation period should have been started earlier and ended later. Failure to do this resulted in incomplete operational statistics, as some of the congestion remained at the end of the simulation period. This could be accounted for in an approximate way by factoring vehicle hours up to a common level of vehicle miles for each alternative.

- The geographic boundaries of the study area were drawn too narrowly. None of the analyses fully addressed the critical issue of the potential diversion of traffic from the freeway, and the impact of various freeway control measures on traffic operations on the adjacent street system. The various models produced useful information on the operations of the freeway proper. They dii not, however, provide a true picture of the corridor overall. Given the level of anticipated trafffc demand, current congestion patterns and the nature of the corridor, this issue clearly needs to be addressed.

- The results of the various simulations indicated clearly that at some point in the relatively near future, the level of service at the freeway is going to become unacceptable, even with the introduction of certain TSM measures. The analysis does not, however, provide any guidance as to the level of trafffc demand when this is likely to occur. It would be useful to conduct some "stress tests' based on incremental increases in traffic demand (say 2-percent, 4-percent, 6-percent, 8-percent, etc.) to determine at what level such options as ramp-metering or truck

restrictions might cease to have value. This, in turn, would provide some indication of the probable "useful life" of such investments as ramp-metering absent a major investment in new construction.

- The limited amount of data on current speeds and travel-times provided only a partial basis for calibration of FRESIM. Desirably, more information should be available to permit more effective calibration of the driver-sensitivity and related parameters of the model.

CASE STUDY #2: NEW YORK/NEW JERSEY

The George Washington Bridge/Cross-Bronx Expressway (Eastbound) Between The G. W. Bridge Toll Plaza and White Plains Road.

The second case study covered a specialized analysis of the I-95 George Washington Bridge/Cross Bronx Expressway (eastbound) corridor. The analysis focused on the use of the FREQ and FRESIM models as alternative approaches to the management of freeway incidents.

Study Location:

The study covered a 5 1/2-mile (8.8 km) section of heavily traveled freeway running eastbound from the toll plaza located at the western end of the George Washington Bridge in New Jersey, across the bridge and along the Cross Bronx Expressway in New York as far as White Plains Road.

The bridge is the busiest facility of its type in the world, carrying roughly 300,000 vehicles per day on two levels. The upper level carries four lanes of traffic in each direction and the lower level carries three lanes in each direction. A complex system of ramp connections links the bridge at its western end to the Cross Bronx Expressway and I-8. Toll plazas for both levels of the bridge are located on its western approaches.

The entire facility is extremely congested. There are no shoulders on the bridge nor on the section of freeway immediately east of the bridge; the remainder of the freeway has only limited width shoulders. Traffic accidents, stalls, and breakdowns are common in this section and any incident normally results in the Mocking of one or more lanes. Construction of additional lanes and/or emergency turnouts is virtually impossible. Consequently, it is important that other means be examined to hold the impact of incidents to a minimum, including the use of closed-circuit TV cameras to spot breakdowns rapidly, changeable message signs and similar methods of providing drivers with enhanced information, and the positioning of additional tow trucks at strategic locations. The FREQ and FRESIM models were used to test some possible schemes.

Figures 31 and 32 illustrate, respectively, the location of the overall study section, and the detailed geometry for the lengths simulated by FREQ and FRESIM.

Application of Models:

A 4-h period was simulated using FREQ, from 6:00 AM to 1O:OO AM, covering the entire 5 1/2 -mi (8.8 km) of the eastbound freeway. Both levels of the bridge were included. The 4-h period covered the buildup and dissipation of the typical morning peak congestion. The model runs involved simulation of an incident of varying duration (15 to 45-min) in the vicinity of Jerome Avenue, approximately 2-mi (3.2 km) from the eastern end of the study section. The incidents were assumed to block one lane completely.

A shorter section involving only the upperdeck of the bridge was simulated using FRESIM. The simulation runs covered 2-h (6:00 AM to 8:00 AM). The purpose of the analysis was to examine the particular operating problems created on the upper deck of the bridge following the occurrence of a brief (30-min) and longer (50-min) incident in the center lane of the bridge proper close to the downstream end of the bridge proper.

Model Callbration and Evaluation of Existing Condltions:

Data on freeway geometry, traffic volumes, incident frequency, and duration travel times and signing were obtained through TRANSCOM, an organization estabiished by a consortium of agencies in the greater New York City metropolitan area to coordinate traffic management activities in the region.

The process of model calibration was essentially similar to that described for case study #1.

In the case of the FREQ model, capacities were estimated for each subsection simulated and adjusted until 15-min model volumes matched those observed in the field. In the case of the FRESIM model, the car-following sensitivity factor was adjusted to reflect a more aggressive level of driver behavior until 15-min model volumes again matched those observed in the field.

Evaluation of the Impact of Incidents:

Estimates were first made of the average duration of typical incidents in the study section. The estimates were based on data from service patrol records and focused on average response and clearance times once an incident had been detected. A separate set of estimates was then made (based on experience elsewhere) of the likely detection and verification times associated with different automated systems and incident management arrangements. Both sets of estimates are described in the case study *#2, Incident Management Alternatives Analysis Report.*
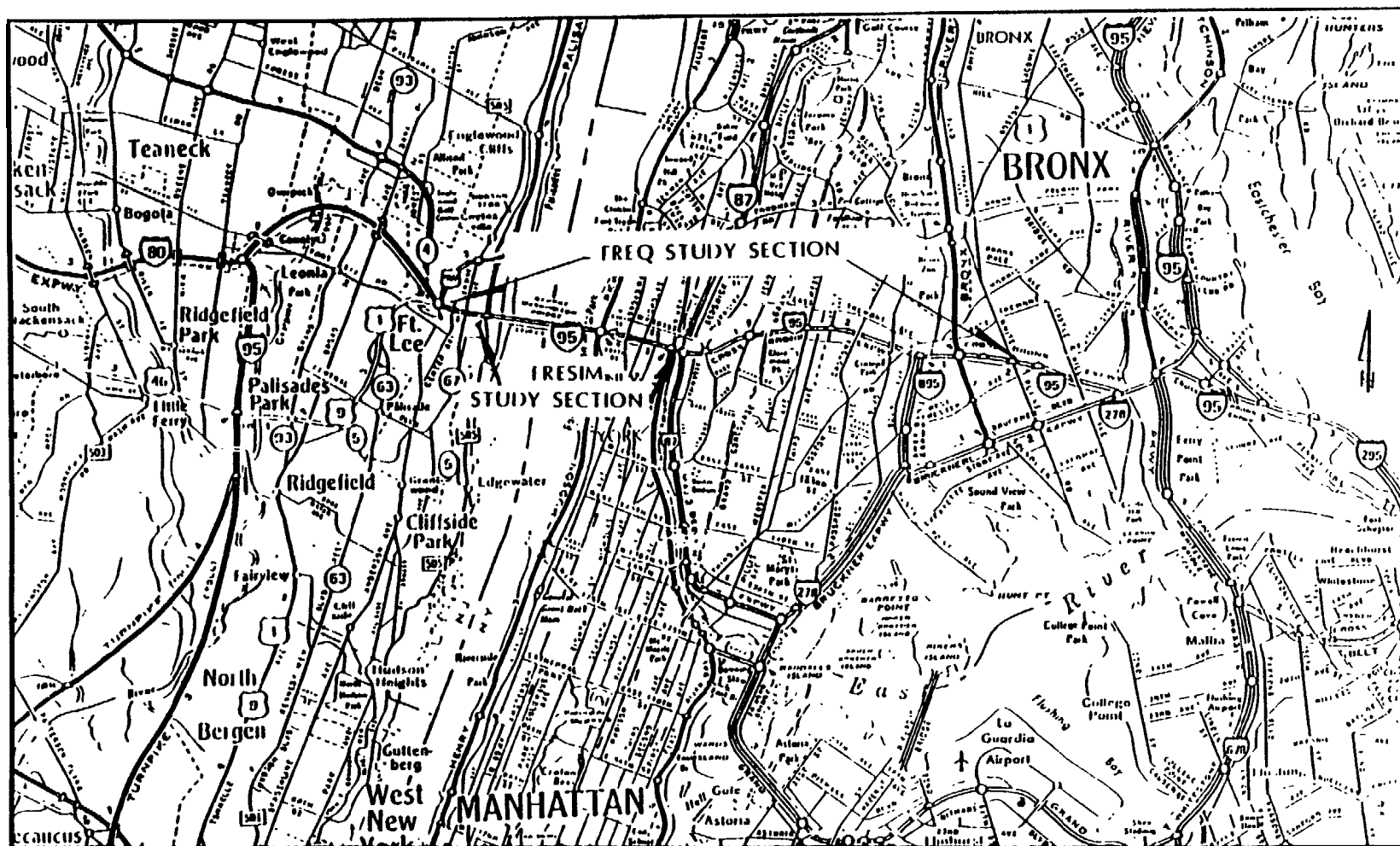
Figure 31. Location of George Washington Bridge site, New York/New Jersey.

BEGIN SECTION

UPPER LEVEL
TOLL PLAZA

UPPER LEVEL ——→

GEORGE
WASHINGTON
BRIDGE

FRESIM Study Section

FRESIM Study Section

PIP ON

HUDSON
TERR

(NO VOLUME)

HENRY
HUDSON
PARKWAY

HARLEM
RIVER
DRIVE

ON FROM
LOWER
LEVEL

MAJOR
DEEGAN
EXPRESSWAY

BEGIN SECTION

LOWER LEVEL
TOLL PLAZA

LOWER LEVEL ——→

HENRY
HUDSON
PARKWAY

HARLEM
RIVER
DRIVE

EMERGENCY
OFF-RAMP

HENRY
HUDSON
PARKWAY

NOT
TO
SCALE

N

CONT. FROM
ABOVE

END

MAJOR
DEEGAN
EXWAY

ALEXANDER
HAMILTON
BRIDGE

JEROME

WEBSTER

3RD AVE

SHERIDAN
EXPRESSWAY

177TH ST

WHITE
PLAINS

Figure 32. George Washington Bridge site: detailed geometry for simulation studies.

Figure 33 summarizes the results of these analyses. Estimates are shown in the table for average detection, verification response, and clearance times for each of a series of incident management strategies. Each strategy involved various combinations of automated detection and verification technology, pre-planned response and management arrangements.

Projected reductions in total incident duration compared to current conditions, range from over 20-min for a "total incident management program" to around 4-min for simple subprograms involving only lane control or automated loop detection.

Clearly, the minutes in figure 33 tell only part of the story. Equally important is the impact that improvements in incident management have had on the total delay incurred by vehicles traversing the corridor. Two of the simulation models, FREQ and FRESIM, were used to evaluate this issue for the George Washington Bridge study location.

The FREQ model was used to estimate on a macroscopic level the impact of a single-lane incident of varying duration, occurring toward the downstream end of the study section. The FRESIM model was used to study in detail the impact of a similar incident on the bridge proper.

Results of FREQ Analysis:

The FREQ model was used to approximate the effect of a single-lane incident occurring in the vicinity of Jerome Avenue, roughly 5-mi from the end of the study section. Four incidents were evaluated, lasting for total periods of lbmin (7:00 to 7:45 AM), and 60-min (7:00 to 8:00 AM). In each case, the incident was assumed to reduce the capacity of the three-lane section of freeway involved by 50-percent based on evaluations of the impact of incidents on throughput from other studies. The effect of the incident was represented by inputting this capacity reduction to the FREQ model for the subsection involved for the duration of each incident.

Figure 33 shows the resultant variation in delay (measured as total vehicle hours of travel for the entire study section and study period) with incident duration. The analysis suggests that a short (15-min) incident has relatively little effect on total delay, but longer incidents have an impact that increases significantly as the duration of the incident lengthens.

The results summarized in figures 33 and 34 were then combined together to provide an approximation of the potential delay savings likely to be achieved through various incident management strategies. For example, figure 33 indicates that experience suggests that installing CCTV cameras may be expected to reduce the average duration of an incident from the current level of 44-mln to 36-min. Interpolating from figure 34, this suggests a reduction in total vehide hours of travel for a typical, one-lane incident from 6,200 vehicles hours in the morning peak period (for an incident 44-min in duration) to 5,700 vehicle hours (for an incident 36-min in duration). This represents a savings in delay of 500 vehicle hours.

Survey data for the study section indicated a conservative average of four incidents per week during the morning peak period in the eastbound direction. Extrapolated to 52 weeks per year, that yields an estimated savings of 104,000 vehicle hours/year (500 x 4 x 52).

Strategy	Detection	Verification	Response	Clearance	Total
For Accidents					
Current	8	6	10	20	44
Loops Only	4	6	10	20	40
CCTV Only	6	2	8	20	36
Loops & CCTV	4	2	8	20	34
Add'l Wreckers	6	4	6	15	31
Acc. Invest. Sites	8	6	10	12	34
Access Points	8	6	8	18	40
Lane Control	8	6	6	20	40
For Other Incidents					
Current	10	6	10	15	41
Cellular Call-in	5	6	10	15	36
Loops Only	4	6	10	15	35
CCTV Only	6	2	8	15	31
Loop & CCTV	4	2	8	15	29
Add'l Wreckers	8	6	6	10	30
Acc. Invest. Sites	10	6	10	10	33
Lane Control	10	6	6	15	37
TOTAL PROGRAM	4	2	5	8	19

**Figure 33. Estimated average Incident duration under various
Incident management strategies.**

159
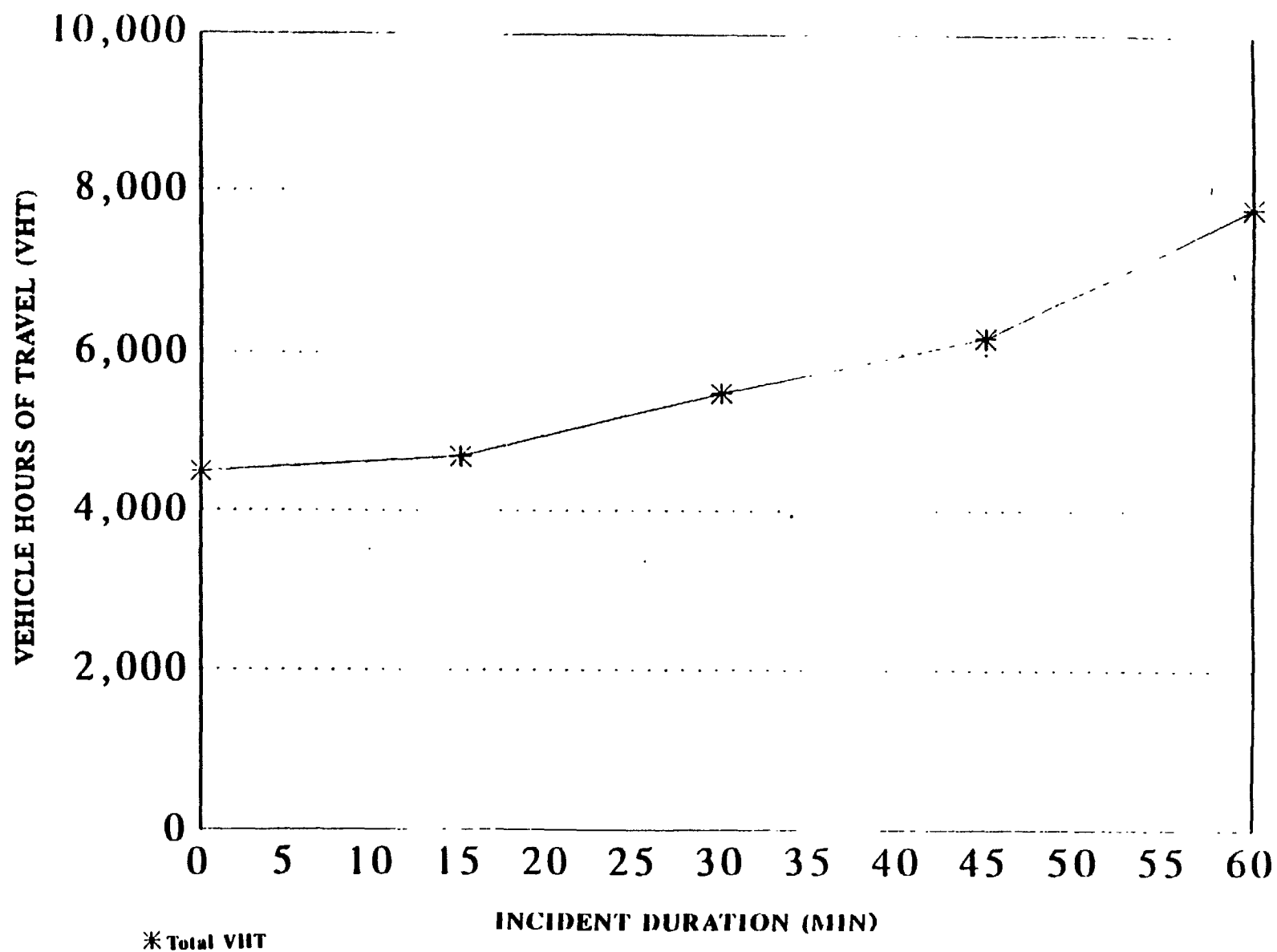
Figure 34. George Washington Bridge site: FREQ analysis (a.m. peak period eastbound, incident in vicinity of Jerome Ave.), variation in delay with incident duration.

Similar calculations might be made both for the other strategies listed in figure 33, and for incidents of various durations occurring at other locations.

Results of FRESIM Analysis:

The FRESIM model is designed to simulate the microscopic response of traffic to an incident directly. It includes a provision to vary the location and duration of an incident along the total section of freeway simulated, and also to simulate the effect of a changeable message warning sign located at a specified distance upstream.

Both of these options were used to examine the impact of an incident occurring in the middle lane of the upper deck of the George Washington Bridge during the morning peak period. Four scenarios were tested, involving incidents 30-min and 50-min long, with and without a warning sign located 4,500 ft (1,376 m) upstream from the incident site.

Figure 35 illustrates the location of the incident. Figure 36 illustrates five speed contour plots derived from the FRESIM runs - one for each incident scenario, plus a base-case involving no incident. Figure 38 summarizes a set of aggregate statistics for the FRESIM subnetwork, again covering each of the four incident scenarios plus a base-case.

Examination of the speed contour plots in figure 35 indicated significant upstream congestion in the base case with no incident, with significant queuing and speeds dropping to less than 10 mi/h (16.1 km/h). For both a 30-min and a 50-min incident with no weaving sign, the congestion worsened markedly, particularly for the longer incident with speeds dropping to less than 10 mi/h (16.1 km/h) upstream of the incident site for over 45-min. Introduction of an upstream waving sign for the 50-min Incident tended to smooth the flow around the incident itself, but did not significantly reduce the level of upstream congestion. The effect of introducing a warning sign in the case of the shorter, 30-min incident, however, is very marked. Flow was maintained at a 40 mi/h (64.4 km/h) pace around the incident itself and speeds upstream never fell below those in the no-incident base case.

Figure 37 summarizes an aggregate set of network statistics based on the flve FRESIM analyses. They support the pattern noted above. Delays were highest, speeds lowest, and vehicle miles of travel lowest for the longer incident, with the introduction of a drawn warning sign having had a beneficial, but not very significant effect. The introduction of a warning sign for the shorter incident had the effect of virtually restoring traffic performance to its original condition without the incident.

Lessons Learned:

Again, several important lessons may be drawn from the analysis.

10,000 | 560 | 425 | 5570' | 3070' | 795 | 800' | 1040'

TOLL PLAZA

1 2 3 4 5 6 7 8

PtP

HUDSON

HARLEM FROM LOWER DECK

DEEGAN

– – Location Of Incident

N

1 ft.=0.305m

NOT
TO
SCALE
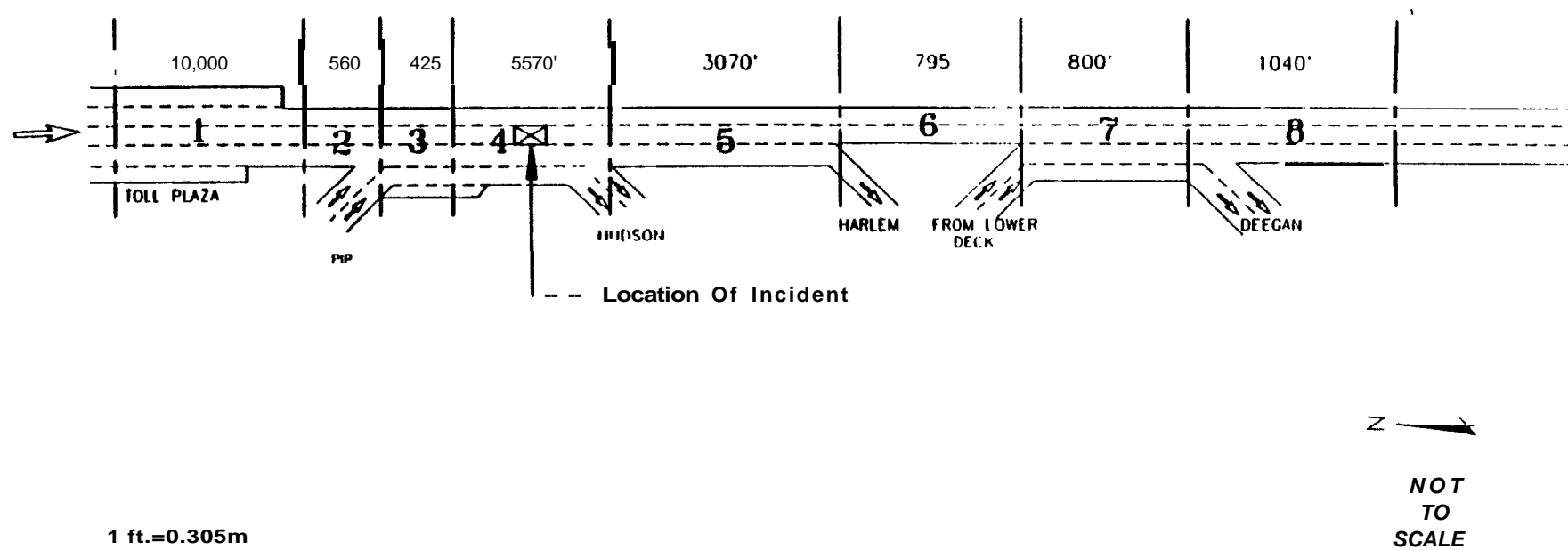
Figure 35. George Washington Bridge site: FRESM study section, showing location of incident.

FRESIM SPEED CONTOUR DIAGRAMS
UPPER DECK OF GEORGE WASHINGTON
MEMORIAL BRIDGE

A

B

C

D

E

1 mi/h = 1.61 km/h
1 ft. = 0.305 m

Figure 36. George Washington Bridge site: FRESIM speed contour plots for alternative incident scenarios.

		Total Mi of Travel	Total Vehicle Min of Travel	Average Speed (Mi/h)	Average Delay Time/ (Min/veh-mi)
Alt A:	Base Case, No Incident	51,228	113,826	27.0	0.62
Alt B:	Medium-Term (50-min) Incident No Advance Warning	49,684	148,225	20.1	1.35
Alt C:	Medium-Term (50-min) Incident Advance Warning at 4,500 ft	49,882	138,869	21.5	1.17
Alt D:	Short-Term (30-min) Incident No Advance Warning	50,975	122,913	24.9	0.80
Alt E:	Short-Term (30-min) Incident Advance Warning at 4,500 ft	51,211	114,172	26.9	0.62

1 ft – 0.305 m
1 mi – 1.61 km
1 mi/h - 1.61 km/h

Figure 37. George WashIngton Bridge site: aggregate statistics
for FRESIM analysis

Recommended Improvement: The analyses using the FREQ model, while crude, suggest that significant savings may accrue from the implementation of more effective incident management strategies. in the case of the specific example cited here, it appears that implementation of a CCTV system may reduce morning peak delay by over 100,000 vehicle hours/year in one direction. Other measures not discussed here but covered in the detailed case study report may be expected to have an even greater effect.

The FRESIM model analyses suggest that even under very heavy flow conditions, notification of drivers of the presence of an incident well upstream of the incident site has a marked effect on smoothing traffic flow and reducing delay for an incident of roughly 30-min in duration. The effect is beneficial, but less marked for a longer incident lasting 50-min.

The Analysis Process: Three major conclusions may be drawn from the case study concerning the analysis process:

- Again, as in the case of the first case study, the amount of field data available to calibrate the two models was very limited. The calibration was primarily based on knowledge of queuing patterns. It would have been desirable to have more speed/travel-time data available.

- Both models were capable of reproducing the effect of an incident and appeared to yield realistic results for incidents of various durations. The approach in the case of FREQ, however, was relatively crude, involving simply a reduction in the capacity of the subsection where the incident occurred. FRESIM has the ability to model the response of the traffic stream to an incident in considerably more detail, and appears to do so very realistically.

- It again appears that the boundaries of the study area may have been defined too narrowly and that the simulation period chosen was too short to reflect the full extent of the delay in the study section and the consequent reduction in delay due to various management strategies.

CASE STUDY #3: MILWAUKEE, WISCONSIN

I-94 (Eastbound) Between U. S. 45 and I-43

Study Location:

The third case study focused on a 10.5-mi section of l-94 (eastbound) west of downtown Milwaukee, Wisconsin, between U.S. 45 and I-43. The section includes three complex interchanges: the zoo interchange to the west, connecting l-94 with U.S. 45 and I-894: the stadium interchange in the center of the section; and the Marquette interchange to the east connecting I-94 with I-43.

Figures 38 and 39, respectively, illustrate the location of the study section and its existing lane configuration.

The freeway varies between two and three lanes in width, with several points of serious lane discontinuity. Only the median and center lanes are continuous throughout the section. It includes both left- and right-hand entrance and exit ramps, several of which are very close together. There is a 3-percent upgrade towards me eastern end of the section.

Traffic volumes are high, ranging from 132,000 to 154,000 vehicles/day on an average weekday, with AM peak hour flows in excess of 6,000 vph in the eastern half of the section.

Serious congestion exists during the AM peak at a number of points within the section, particularly through and to the east of the stadium interchange. This congestion spills back regularly as far as the zoo interchange.

Four entrance ramps are currently metered at 84th, 68th Hawley Road and 35th Street during the AM peak. A bus bypass lane is provided at 68th Street.

Application of Models

All four models were used in the case study. Their areas of application were generally similar to those described earlier in Case Study #1.

The HCS software was used to evaluate the capacity of individual sub-sections of the study section, and to help determine desirable lane configurations and lane balance.

The two macroscopic models, FREQ and FREFLO were used to evaluate current operations over the entire study section, and to assess three alternative improvement schemes.   in each case, traffic was simulated over a period of 2-h and 45-min, starting at 6:15 AM and ending at 9:00 AM. Both current and projected future volumes were simulated, with the future volumes being based on growth factors varying from 13-percent to 55-percent for the entrance to the mainline section and specific ramps for the period 1989-2010.

The FRESIM model was used to evaluate traffic operations at a detailed level for the central segment of the study section where congestion was most severe (See figure 39).

Data on existing geometry, traffic controls, existing and projected future traffic volumes: and travel times were provided by the Wisconsin Department of Transportation.

Model Calibration

The model calibration process followed the same general steps described earlier for Case Study #1, with a number of additions in the case of FREQ and FREFLO.
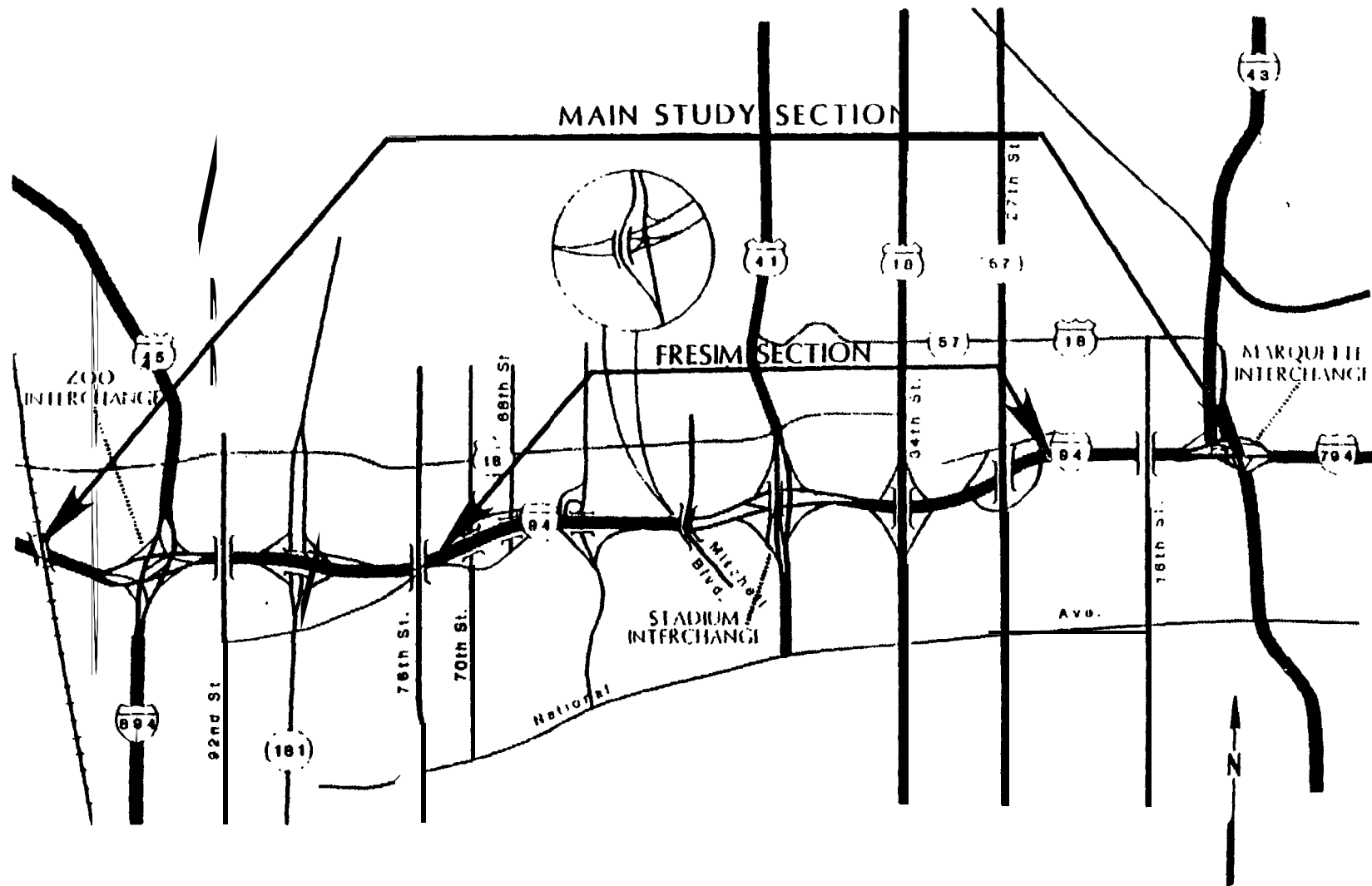
Figure 38. Location of I-94 study section in Milwaukee, WI
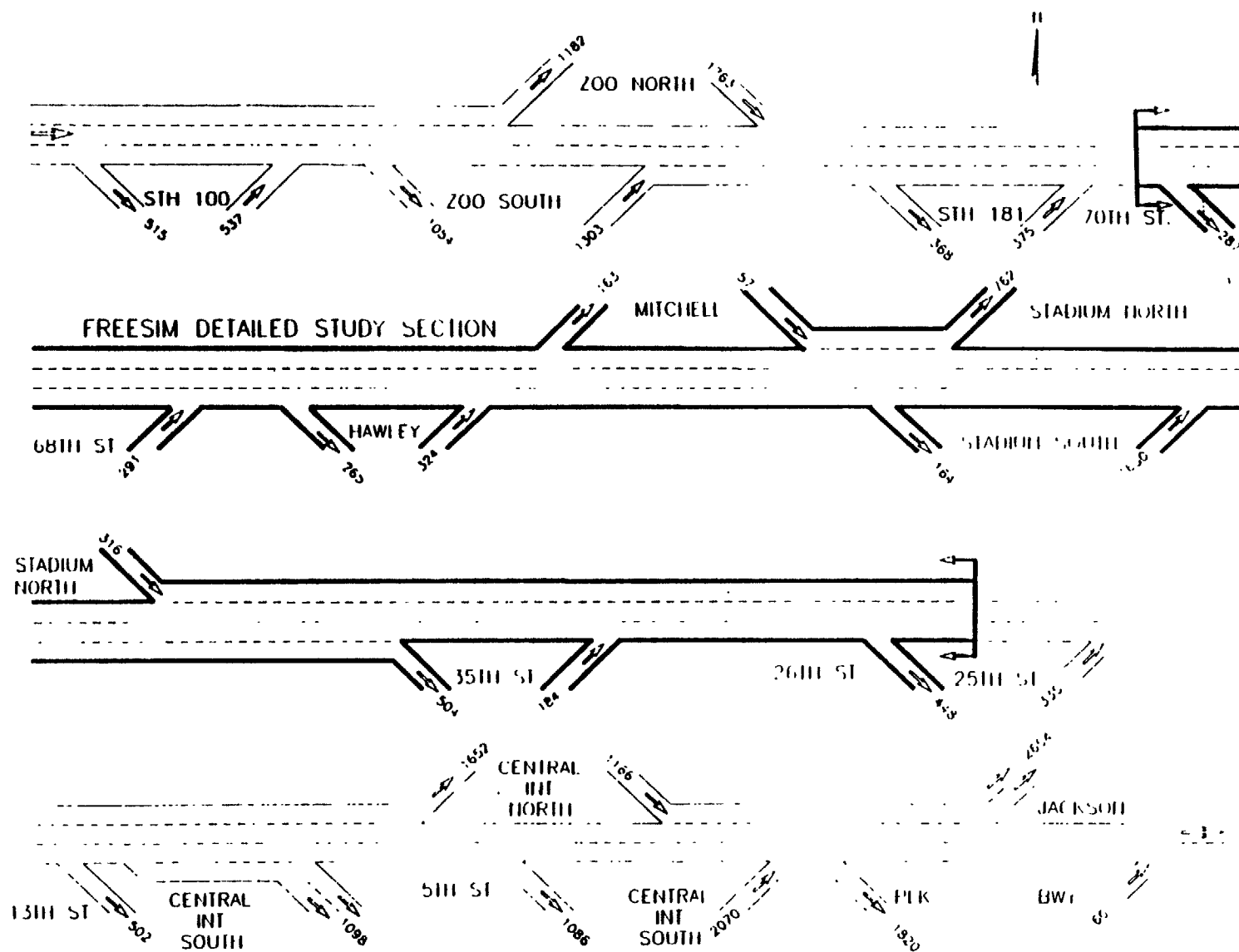
Figure 39. Milwaukee I-94: existing lane configuration, 1989 a.m. peak hour volume counts.

For both FREQ and FREFLO, capacities were first estimated for each subsection and used as initial input to the models. The resultant 15-min section-by-section volumes were then compared with equivalent field data.

As in the case of the Seattle case study, it was found from the field data that flow rates well in excess of 2,000 vphpl were observed regularly across the study section. This is illustrated in figure 40, which depicts a plot of average speed against volume based on data collected for the I-94 site. Note the significant number of observations of flow fates between 2,000 vphpl and 2,400 vphpi with equivalent speeds in excess of 30 mi/h (48.3 km/h).

Based on this data, the capacity of a basic freeway segment within the study section was again increased from the standard figure of 2,000 pcplph, specified in the Highway *Capacity Manual,* to a level of 2,100 vphpl. This figure was used as the basis for all subsequent FREQ and FREFLO runs.

Using the higher capacity figure yielded simulation volume output by section, which reproduced the equivalent field volumes reasonably well.

Checks were then made of speed profiles generated by FREQ, FREFLO, and HCS with equivalent field data for selected 15-min periods. Figure 41 illustrates one such set of profiles for the period 7:15 AM to 7:30 AM. As in the case of the Seattle case study, the correspondence was far from perfect, but was generally acceptable, with the FREQ model tending to replicate the field observations somewhat more closely than FREFLO.

Two other calibration check were also made for FREQ and FREFLO.

The first focused on a comparison of density contour plots for each model with actual queuing patterns formed in the field. The patterns observed in the model output in each case represented closely the patterns observed in the field.

The second comparison focused on FREQ only. As part of the modeling process, FREQ creates a simulated O-D table. The ramp-to-ramp O-D patterns from the model were compared with the results of a 1988 freeway O-D survey conducted by the South East Wisconsin Regional Planning Commission. The results of this comparison are summarized in figure 42. Roughly 50-percent of the modeled interchanges showed these figures are a correspondence within ±30-percent of the field observation. Again, a far from perfect match, but indicative of an acceptable level of correspondence for analysis purposes.

In the case of FRESIM, no attempt was made to modify the default values of any of the model calibration parameters, primarily due to a lack of necessary field data the volume, speed and density contour output generated by the model were compared with equivalent field observations following the approach outlined above. In each case, acceptable levels of correspondence were considered to exist between the model output and equivalent field data for the purposes of the case study.

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FHA CONGESTED CORRIDORS

MILWAUKEE I-94 SITE

1 mi/h = 1.61 km/h

VOLUME (VEH/LANE/H)
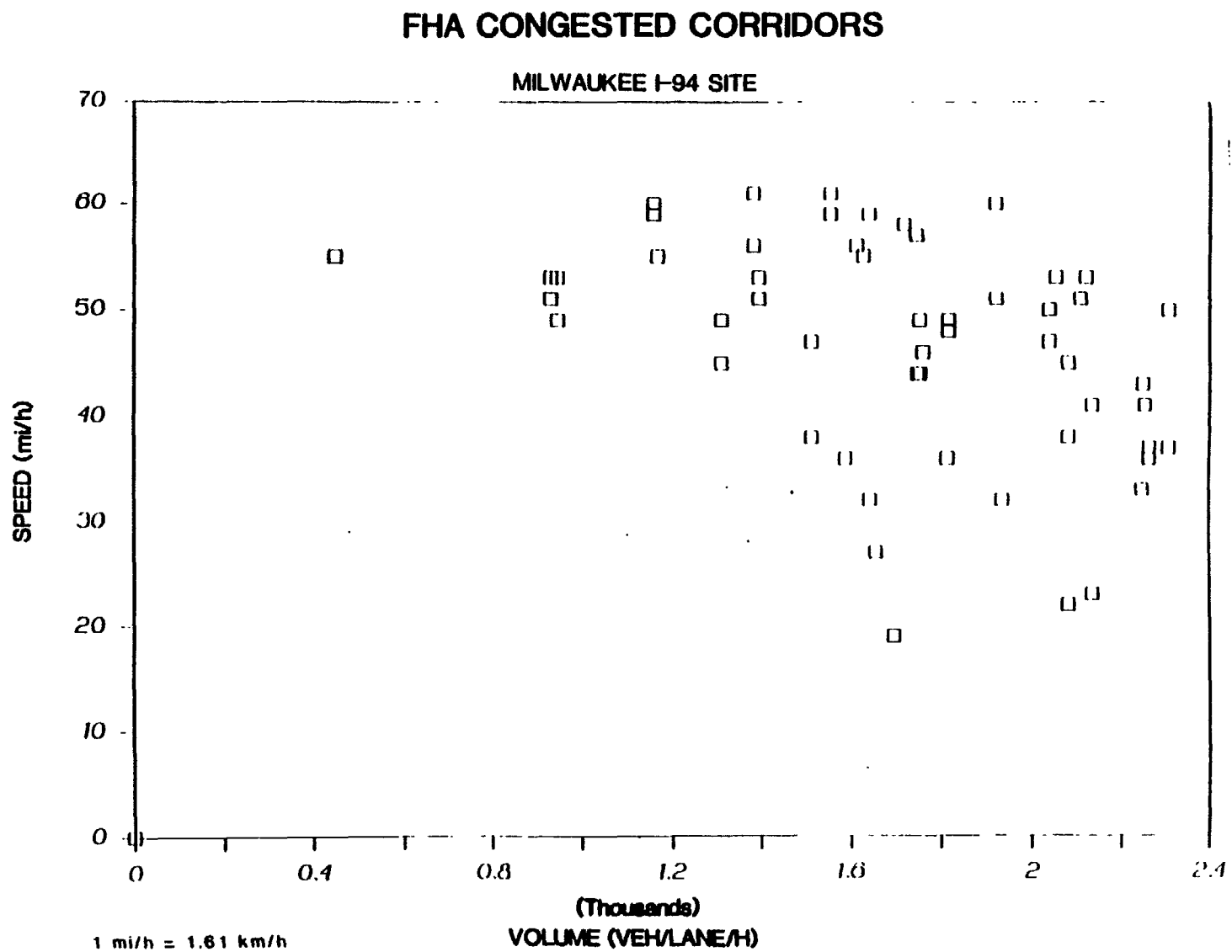
Figure 40. Milwaukee I-94: speed-volume relationship derived from section and travel time data 2 on I-94.

MILWAUKEE I-94

YEAR 1989 EXISTING CONDITIONS
7:15 - 7:30 A.M. Speed Profiles

SPEED (mi/h)

70

60

50

40

30

20

10

0

STH 100   Zoo   70 St   Mitchell   Stadium   35 St   Central   Jackson

SUBSECTION

⊘ ACTUAL   ◆ FREQ   ⊸ FREFL○   △ HCM

mi/h =   61 km/h
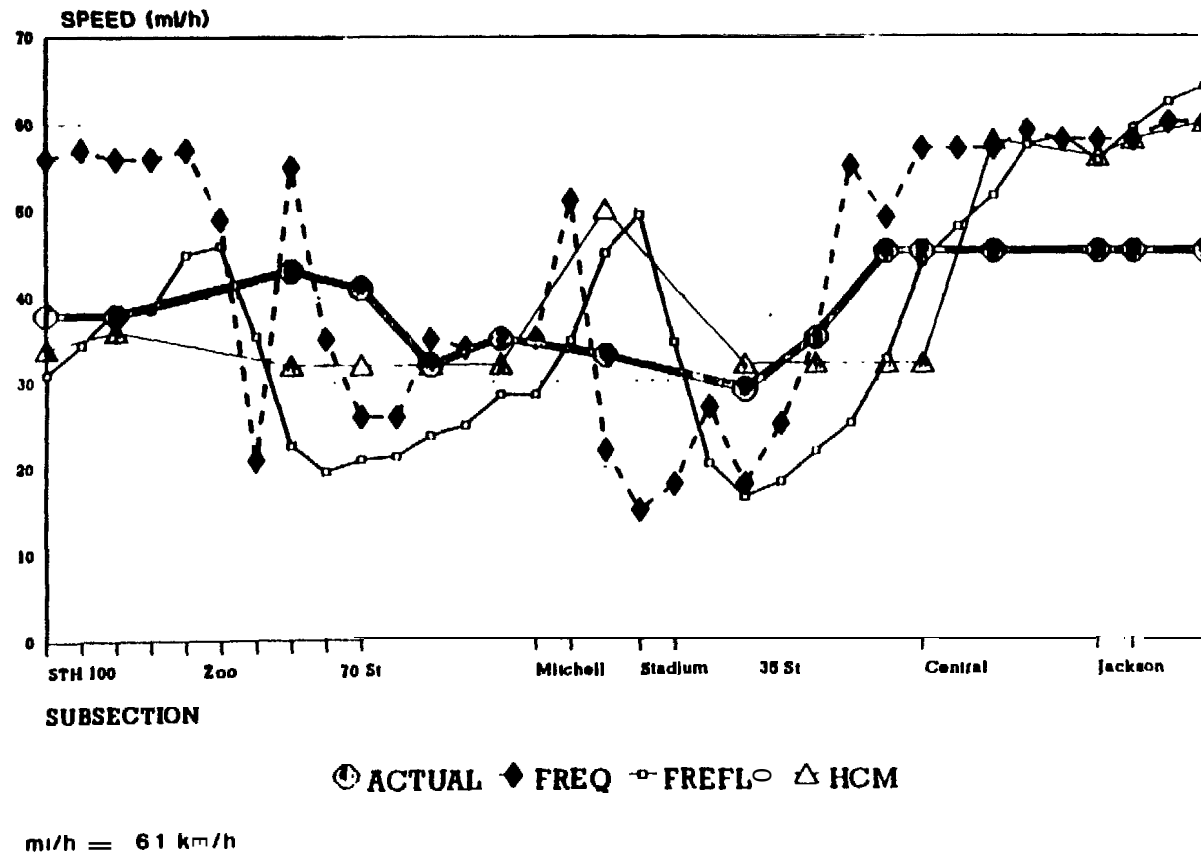
Figure 41. Milwaukee I-94: 1989 existing conditions, 7:15-7:30 a.m. speed profiles.

TO DESTINATIONS

FROM	84th St.	70th St.	Hawley Road	Mitchell Blvd.	Stadium W/S	W/N	35th ST.	26th St.	13th St.	W/S	W/N	Central W/E
ORIGINS	4	5	6	7	8	9	10	11	12	13	14	15 18
1 & 2 W/E	4.5/5.2 %	5.5/9.9 %	2.9/6.6 %	1.9/3.3 %	2.5/2.9 %	12.0/9.1 %	4.8/6.8 %	5.0/7.3 %	5.4/2.5 %	10.3/5.8 %	15.6/13.2 %	37.0/27.4 %
3 S/E	3.5/5.9	5.7/5.7	3.0/3.6	1.4/2.1	2.2/2.3	10.6/14.4	4.3/6.9	4.9/6.4	5.4/4.6	10.0/3.9	15.2/17.7	1.275471698
4 N/E	······	5.6/5/2	3.0/4.3	1.2/3.9	2.2/3.2	10.7/8.4	4.2/8.8	4.8/4.7	5.4/4.5	10.1/6.9	15.1/9.7	33.9/34.6
5 84th St.		5 6	3.4	1.1/1.8	2.2/4.6	11.2/12.8	4.5/9.2	4.5/2.8	5.6/5.5	10.1/7.3	15.7/23.9	35.9/32.1
6 68th St.			3.5/2.0	1.2	2.4/5.9	11.6/1.0	4.7/14.7	5.8/5.0	5.8/4.0	11.6/10.9	16.3/24.8	37.3/31.7
7 Hawley Rd.			····	1.5	3.1	12.3/14.3	4.6/11.4	6.2/7.2	6.2	10.8/5.7	16.9/25.7	38.5/35.7
8 Mitchell St.						8.3/9.1	8.3	8.3	8.3	8.3/27.2	16.7/45.5	41.7/18.2
9 S/E							5.9/6.1	6.4/3.0	7.4/4.5	13.5/3.1	20.4/53.8	46.3/29.5
10 N/W							6.3/2.3	6.3/8.5	7.5/4.3	13.8/19.8	20.0/10.6	46.4/54.5
11 35th St.								6.7/1.4	6.7/6.9	13.3/8.4	23.3/48.6	50.0/34.7
12 25th St.									8.8/1.3	16.2/19.2	23.5/50.0	51.4/29.5

Key: Numbers represent percentage of traffic from a given origin ramp to each destination ramp.
FREQ estimates are to the left of the slash, survey estimates are to the roght (FREQ/SURVEY).

Figure 42. Milwaukee I-94 comparison of model (FREQ) ramp-to-ramp O-D interchanges with equivalent survey data.

Evaluation of Existing Conditions and Development of Alternatives:

The final calibration model runs were combined with observations of actual traffic operations to serve as-a starting point for the development of alternative improvement schemes.

Each of the models suggested that the current congestion problems were a result primarily of serious lane disoontinuities, lack of continuous mainline capacity and heavy weaving resulting from the combinations of left- and right-hand ramps. with the anticipated growth in traffic by the year 2010, the problems would clearly become extremely severe unless major improvements were made at a number of points in the study section.

Three major improvement options were developed.

- **Alternative #1, "Basic Improvement Alternative,"** focused on a minimum set of essential improvements, aimed primarily of improving lane balance, adding several lengths of auxiliary lane to improve ramp maneuvers and minor modifications to three interchanges. An expanded ramp metering scheme was also considered as an option with the alternative being. tested with and without the scheme in operation. The lane configuration for this alternative is illustrated in figure 43.

- **Altemative #2, "Four Bask Lane Alternatives,"** encompassed a systemwide series of long-term improvements designed to create a high quality freeway environment. The improvements included a lane addition throughout the study section, additional auxiliary lane ramp widening and replacement of all left-hand ramps with equivalent right-hand facilities. The alternative included major changes to several interchanges. As an option, the addiion of an HOV lane together with expanded metering was considered, with the alternative again being tested with and without the option in effect This alternative is illustrated in figure 44. It is important to note that transportation policies and objectives in Milwaukee emphasize demand reduction through transit and travel demand management (TDM). The addition of a lane on I-94 could make some of these objectives more difficult to achieve. The preferred alternative must therefore be evaluated using additional data not obtainable through freeway simulation alone.

- **Alternative #3, "Four Bask Lane Altemative WIthout Changes to Zoo Interchange,"** built on the HOV option for alternative #2, but eliminated all changes at the zoo interchange and to the west of that location. This alternative is illustrated in figure 45. The note on transportation policy in alternative 2 is also applicable here.

N

ZOO NORTH

STH 100

ZOO SOUTH

STH 181 70TH ST.

STADIUM NORTH

68TH ST. HAWLEY MITCHELL STADIUM SOUTH

35TH ST. 26TH ST. 25TH ST.

JACKSON

13TH ST. CENTRAL OFF 5TH ST. CENTRAL ON PLK. BWY.
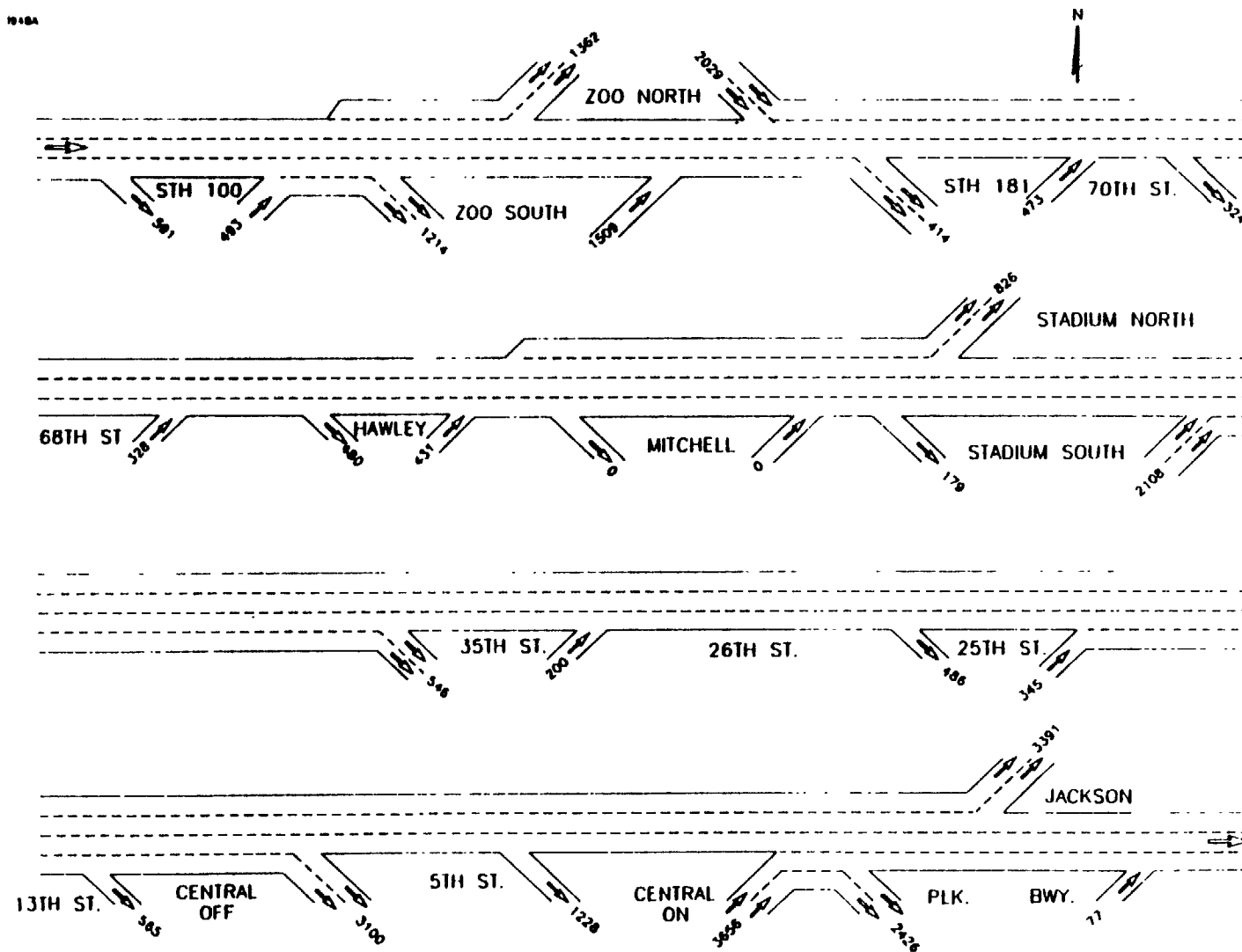
Figure 43. Milwaukee I-94: Alternative 1 - Basic improvement projected a.m. peak hour ramp volumes for year 2010.

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N

Note: This lane would be HOV in four basic lane/HOV alternatives.

STH 100

ZOO

STH 181

70TH ST.

68TH ST

HAWLEY

MITCHELL

STADIUM

35TH ST.

26TH ST.

25TH ST

HOV ENDS

JACKSON

13TH ST.

CENTRAL OFF

5TH ST

CENTRAL ON

PLK.

BWY
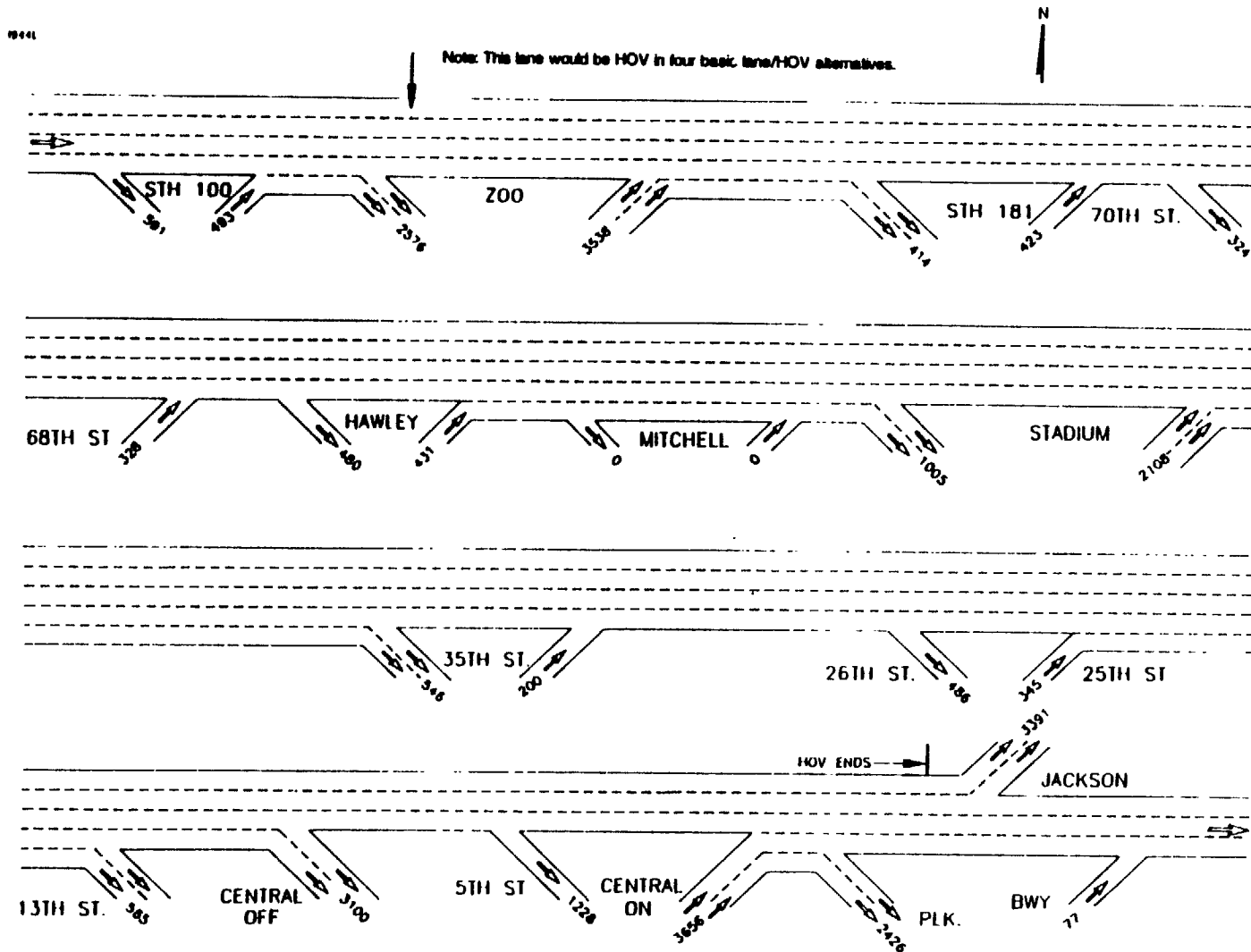
Figure 44. Milwaukee I-94: Four basic lane alternatives projected a.m. peak hour ramp volumes for year 2010.
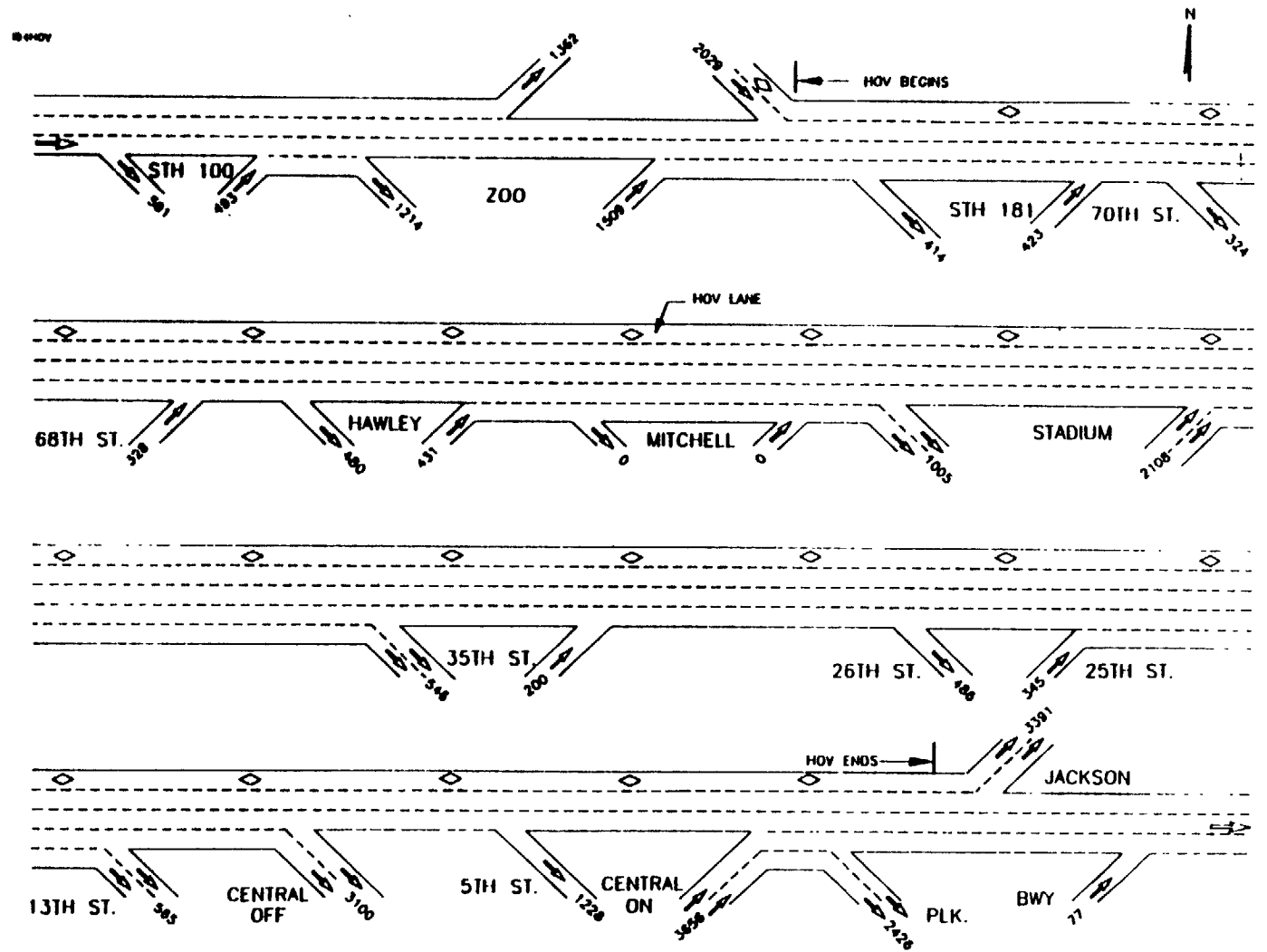
Figure 45. Milwaukee I-94: No change to Zoo alternative projected a.m. peak hour ramp volumes for year 2010.

Evaluation of Alternatives:

Each of the three, alternatives and associated options, plus a no-build option were simulated for the entire study section using FREQ and FREFLO. Simulation runs were made using projected 2010 traffic volumes. All simulations covered the period from 6:15 AM to 9:00 AM.

FRESIM was used to examine in detail the central congested section, with an emphasis on the first two of the three alternatives including both scenarios invotving clock-time metering.. It was not used to evaluate any HOV alternatives because the model does not have the ability to model HOV operations directly. Figure 46 illustrates the lane configurations used for the FRESIM analyses.

The results of these analyses are discussed in detail in the Milwaukee *Alternative Analysis* Report (report III.3 in figure 24).

The results of the FREQ and FREFLO analyses are summarized in figure 47. Both models indicated that alternative #2, 'Four Basic Lane Alternative," yielded the most desirable results in terms of average speeds, person miles traveled, and vehicle miles on the freeway. As indicated earlier, this does not consider the policy implications of highway versus transit-oriented solutions. Therefore, a decision cannot be based on the freeway analysis alone. It was not the purpose of this project to conduct a multimodal alternatives analysis. Implementation of ramp metering for that alternative provided a small, but measurable improvement in freeway performance over operation without metering. It did, however, create excessive ramp delays. Introduction of an HOV facility for the same alternative resulted in a significant reduction in average freeway speed, due to the restriction of one lane for HOV operation. The effect was most marked for the FREQ model runs. However, the effect of the HOV lane dii not include an assessment of its effect on demand. This would have required new runs with the regional travel demand forecasting model.

Performance for each of the other Alternatives and for the no-build option was significantly poorer, though it should be noted mat introduction of ramp metering for both the no-build case and alternative #1 provided a measurable improvement over the equivalent, non-metered situation.

The detailed FRESIM analyses generally confirmed these conclusions (see figure 48). The best freeway performance was achieved with alternative #2; though in this case, inclusion of ramp performance in the calculation of measures of effectiveness indicated mat overall performance was somewhat poorer with ramp metering than without such control. Both versions of alternative #2 yielded substantially better performance than either alternative #1 or the no-build case. As stated earlier, this does not consider transit alternatives.

BASE CONDITION

BASIC IMPROVEMENT ALTERNATIVE

FOUR BASIC LANE ALTERNATIVE
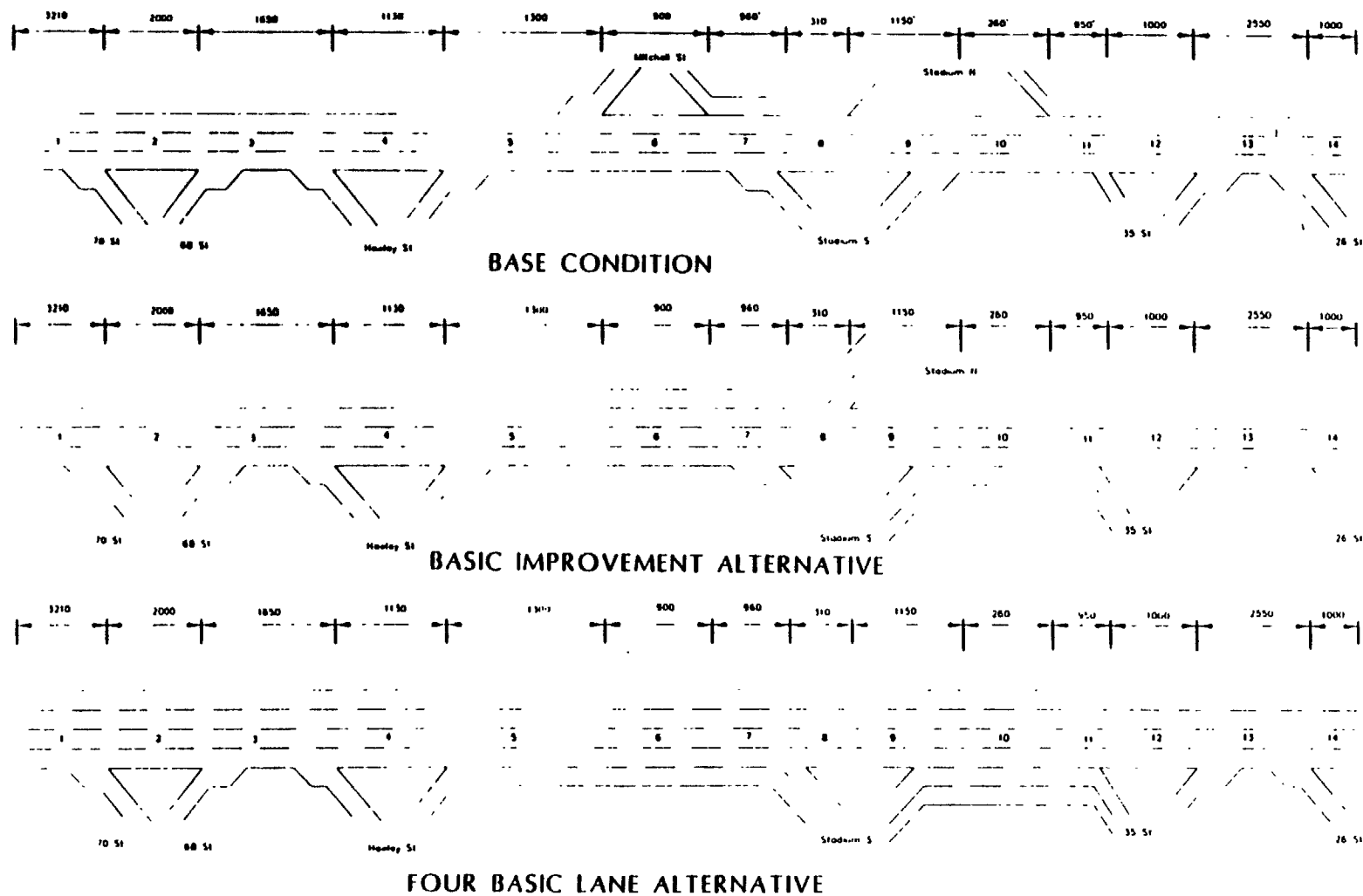
Figure 46. Milwaukee I-94: lane configuration for FRESIM analysis.

SUMMARY OF FREEWAY PERFORMANCE
6:15 - 9:00 A.M.

		AVE. FWY SPEED mi/h	MIN. FWY. SPEED mi/h	FWY.TRAVEL TIME VEH.HRS.	ON-RAMP DELAYS VEH.HRS	TOT.TRAVEL TIME VEH.HRS	DISTANCE TRAVELLED VEH.MI.	PASS.MI.	OVERALL AVE.SPEED mi/h	MAX. V/C	FUEL USED GAL.	CO EMISS. KG.
YEAR 1989												
BASE CONDITION	FREQ	40.3	15.0	2,922	1,068	3,990	117,747	148,361	29.5	1.00	7,476	3,724
	FREFLO	32.4	11.0	3,664	n/a	n/a	118,657	152,474	n/a	n/a	n/a	n/a
YEAR 2010												
NO BUILD	W/O TSM FREQ	27.2	8.0	4,598	5,694	10,292	124,884	140,159	12.1	1.00	10,984	8,196
	FREFLO	20 6	6.0	5,535	n/a	n/a	114,272	147,410	n/a	n/a	n/a	n/a
	W/METERING FREQ	54.7	35 0	2,180	6,982	9,162	119,263	143,015	13.0	1.00	10,771	9,987
	FREFLO	43 4	20.0	2,677	n/a	n/a	116,080	149,279	n/a	n/a	n/a	n/a
BASIC IMPROVEMENT	W/O TSM FREQ	28 8	4 0	4,241	6,098	10,339	121,975	136,515	11.8	1.00	11,415	10,469
	FREFLO	18.2	4 0	5,940	n/a	n/a	107,846	139,119	n/a	n/a	n/a	n/a
	W/METERING FREQ	55 4	35.0	2,169	6,713	8,882	120,101	143,396	13.5	1.00	10,716	9,627
	FREFLO	51 9	25.0	2,253	n/a	n/a	116,899	150,216	n/a	n/a	n/a	n/a
FOUR BASIC LANES	W/O TSM FREQ	52 9	20.0	2,813	0	2,813	148,900	166,649	52.9	1.00	9,183	3,415
	FREFLO	55 5	38.0	2,623	n/a	n/a	145,469	186,928	n/a	n/a	n/a	n/a
	W/METERING FREQ	57.0	55.0	2,578	1,054	3,632	147,019	165,057	40.5	0.93	9,658	4,325
	FREFLO	57 0	42 0	2,505	n/a	n/a	143,638	184,575	n/a	n/a	n/a	n/a
	W/HOV FREQ	26.7	5.0	5,044	30	5,074	134,719	166,032	26.6	1.00	9,500	4,262
	FREFLO	40 6	15.6	3,354	n/a	n/a	136,113	211,595	n/a	n/a	n/a	n/a
NO CHANGE TO 2010	W/HOV FREQ	27 5	11 0	4,869	34	4,903	133,869	161,483	27.3	1.00	9,324	4,640
	FREFLO	28.2	9 7	4,643	n/a	n/a	131,182	196,357	n/a	n/a	n/a	n/a

1 mi/h = 1.61 km/h

Figure 47. Milwaukee I-94: summary of FREQ and FREFLO results.

Alternative	Total (miles)	VMT Total (hours)	VHT Average speed (mi/h)	Delay-Time (min/veh-mi)
Base Case				
Existing Traffic	40,746	1,187.3	34.3	0.79
10% Increase	46,768	1,435.7	26.4	1.15
Basic Improvement				
W/O Ramp Metering	40,942	1.546.3	26.5	1.28
With Ramp Metering	41,218	1,051.2	39.2	0.54
Four Basic Lanes				
W/O Ramp Metering	45,871	806.8	56.9	0.11
With Ramp Metering	42,953	814.8	52.7	0.15

1 mi= 1.61 km
1 mi/h = 1.61 km/h

Figure 48. I-94 Milwaukee, Wisconsin summary of FRESIM results

Lessons Learned:

Recommended-Improvement: All of the models indicated clearly that, while introduction of-measures such as ramp metering would help improve operations, there was no real alternative over the long-term to major reconstruction if significantly improve traffic operations were to be achieved in the future. This involves a combination of widening the mainline cross section, plus relocation and widening of ramps and the addition of lengths of auxiliary lane. However, the benefits of making this improvement must be weighed against emphasizing transit and TDM strategies, based on policy emphasis in the region. Lesser improvements, though they result in enhanced operations compared to the no-build do not appear likely to yield satisfactory operations over the long-run.

The Analysis Process: The simulation analyses provided a useful means of identifying and evaluating alternatives. The process was, however, again constrained by the availability of field data and the ability of the models to represent real world conditions. The points made earlier with regard to case study #1 apply here, namely:

- The time period simulated, though it was over three hours, was still not long enough to accommodate all the demand. This resulted in incomplete evaluations of vehicle hours, since all the travel (VMT) had not been accommodated. An approximation of the unconstrained VHT could be obtained by factoring each alternative's VHT by the ratio of the highest VMT to the alternative's VMT. Choosing a simulation period long enough to allow all the volume to dissipate (induding the no-build condition) would be preferred method of equalizing VMT. This may not always be possible.

- The analysis did not include an evaluation of the impact on arterial streets.

- It would be helpful to evaluate traffic operations at various stages of traffic growth and not just for one target year.

- Desirably, more data should be available to permit a more thorough calibration of the models, particularly of FRESIM.

- No attempt was made to conduct a full-scale cost-benefit analysis.

In addition, two other points should be made.

First, it is apparent that while the three simulation models ail indicated that the same alternative yielded the best operational results, there were significant differences between their detailed output This suggests that under less extreme circumstances they may potentially yield conflicting results.

Second, it is clear that while the HCS methodology is valuable in helping to determine the number of lanes required by subsection and in assessing issues of lane balance, it is not as effective a tool for evaluating the operational performance of a succession of subsections making up a length of freeway.

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CASE **STUDY #4: COLUMBUS, OHIO**

I-71 (Northbound)Between MO and I-670

Study Location:

The fourth of the five case studies involved 5-mi (5 km) section of I-71 (northbound) between the intersections with I-70 and I-670 in Columbus, Ohio.

Figure 49 illustrates the location of the study section.   I-70 and I-71 converge at the southern end of the study section and run together for roughly 3-mi immediately south of downtown Columbus before diverging again, with I-71 continuing north to the intersection with I-670.

The major operational problems were associated with high overall peak period flows and extremely heavy weaving along the sections of freeway immediately to the south and east of the downtown area. Average daily traffic volumes on I-71 ranged from 85,000 vehicles/day at a point just south of I-70 to 126,000 vehicles/day immediately south of the junction with I-670. The I-70/I-71 weaving section carried approximately 113,000 vehicles/day. Peak northbound flows occurred between 5:00 PM and 6:00 PM and averaged 9,800 vehicles/hr. There was roughly 9-percent truck traffic during the peak period.

The geometry of the study section is extremely complex (see figure 50). The cross section of northbound I-71 varies from two to four lanes, with frequent lane drops and additions on both the left- and the right-hand side of the traveled way. There are both left- and right-hand entrance and exit ramps, several of which carry peak-hour volumes of between 1,000 and 2,000 vehicles/h. There is a physical separation between the I-670 and I-71 lanes between Broad Street and Long Street.

Application of Models:

The FREQ and FREFLO models were used to simulate operations within the corridor for a 4-h period from 2:00 PM to 6:00 PM. The HCS routines were used to estimate capacity for, each subsection. FRESIM was used in this case to simulate the entire study section, for a 90-min period starting at 3:30 PM and ending at 5:00 PM. This was the period that appeared to experience the highest levels of congestion.

Data on traffic conditions, geometry, and traffic control were obtained from the Ohio Department of Transportation. A limited number of 'moving-car' travel time runs were made through the study section to assist in model calibration.

No future traffic forecasts were available. Future operational performance was evaluated based on an across-the-board 10-percent increase in traffic.
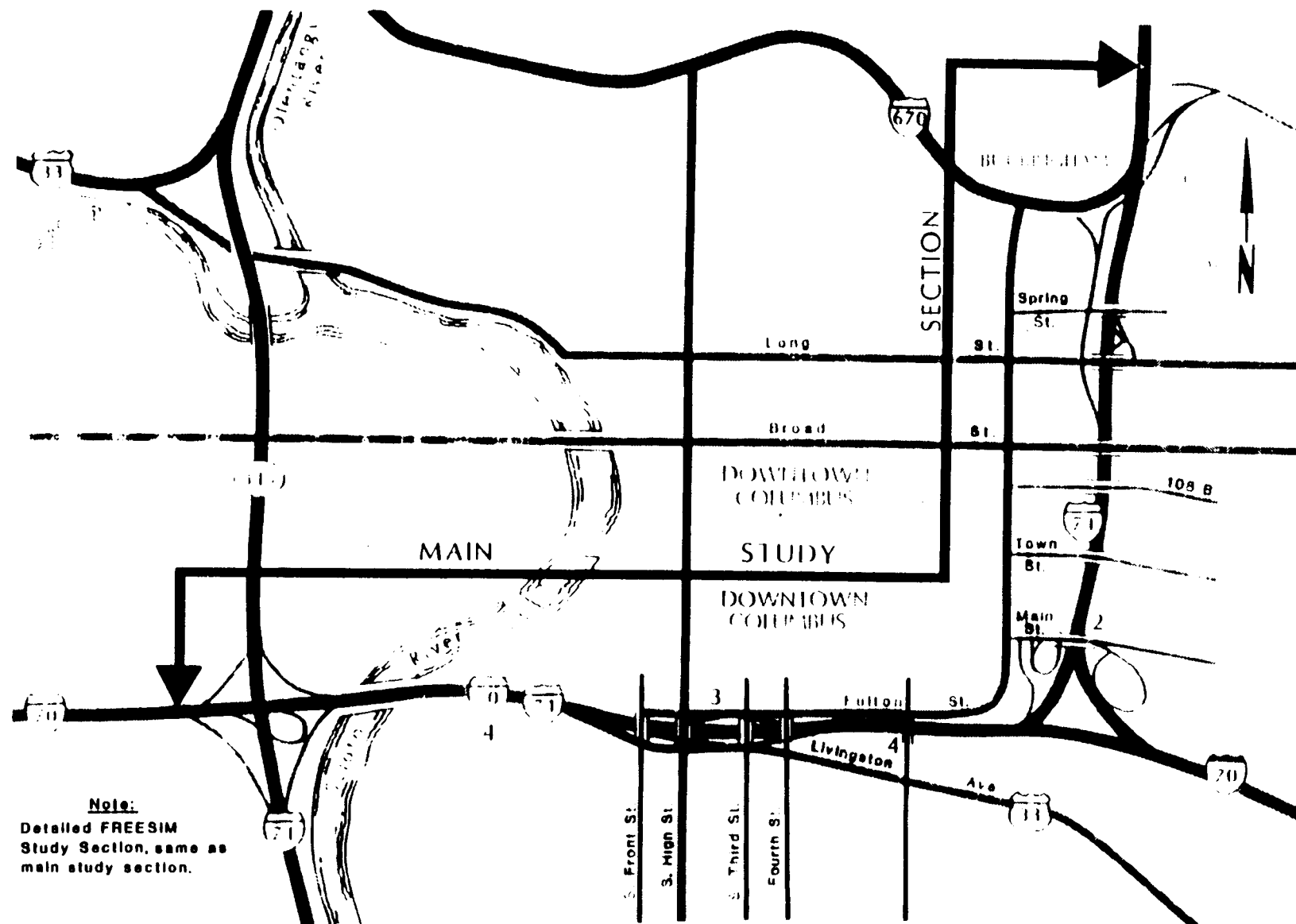
Figure 49. Columbus, Ohio: I-71 study location.

I 70
FROM 315 NORTH
'028

TO 1-71
SOUTH

TO 315
NORTH
862

465

TO I 71
SOUTH
1003

FRONT
579

I-70/71
MAJOR WEAVING SECTION
I 71 (LEFT CURVE)

LIVINGSTON
394

FULTON
805

TO I-70
EAST
414
885

I-670
OFF
809

MAJOR WEAVING SECTION

460

BROAD ST
ON

2306 FROM I-70
WEST

BROAD ST
OFF
534

LONG ST
ON
1393

LEONARD
OFF
132

I 670
ON
1972

NOT
TO
SCALE

//// -Details Coded in FRESIM
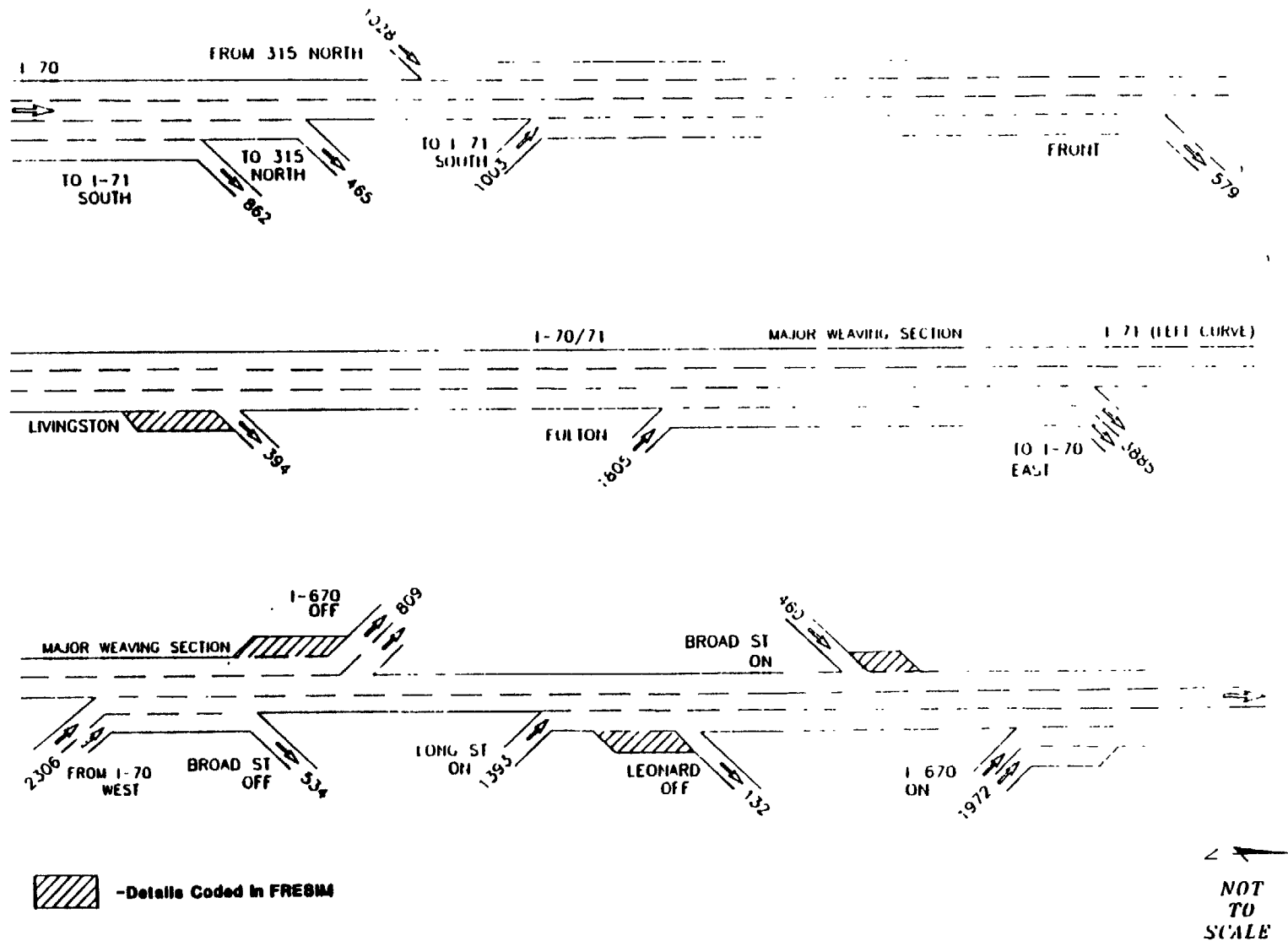
Figure 50. Columbus, Ohio: I-71 existing conditions, 1989 p.m. peak hour ramp volumes.

Model Calibration:

The process of model calibration was similar to that described for the previous case studies. Estimates were first made of the capacity of each subsection using the HCS programs. Runs were then made of FREQ and FREFLO for existing conditions. For both FREQ and FREFLO, the volume output generated by subsection were compared with observed traffic counts. The average 15-min speeds generated by the models were also compared with equivalent, moving-car travel time runs from the field.

Based on these comparisons, a maximum flow level of 2,100 pcplph was again adopted. No other modifications were made in the calibration process.

In the case of the FRESIM model, comparison of the speeds and volumes generated from the model using default calibration values for existing field conditions, with equivalent field data indicated that there was no reason to charge any of the default values specified in the model. These values were used in all remaining runs.

Evaluation of Existing Conditions and Development of Alternatives:

Contour plots for speed and density were generated for both the FREQ and FREFLO model runs made for existing conditions. These diagrams did not indicate extensive congestion, but did show that speeds lower than 40 mi/h were experienced sporadically between 330 PM and 5:00 PM In the weaving section Immediately upstream of the I-70 (west) off-ramp. Similar reductions in speed were also noted between the Broad Street on-ramp and Long Street on-ramp, and over the section of freeway upstream from the I-670 on-ramp.

Detailed examination of traffic flow during the period 330 PM to 5:00 PM using the FRESIM model also did not yield evidence of any serious congestion. Speeds tended to be in the 50 mi/h range, with the exception of the major weaving section between the I-70 (eastbound) off-ramp and the I-670 off-ramp where they fell to 40 ml/h (64.4 km/h). Lane-change counts were very high within this latter section.

Based on the evaluation of the simulation runs for existing conditions, plus field observation of current traffic operations, two potential improvement alternatives were developed. Both were focused on the almost certain need to substantially upgrade the existing geometry of the section at some point in the future if satisfactory traffic operations were to be maintained. The two alternatives were:

- Alternative #1, "I-670 Exit Relocation" (see figure 51) eliminated the existing separation between the I-670 and I-71 lanes between Broad and Long Streets. This required reconstruction of the current overpass and related facilities. The existing ramp from Broad Street to I-670 was relocated to the right-hand side of the combined section. The exit to I-670 then utilized the existing left-leg to the north of Long Street, which lead to the existing collector-distributor segment and then to I-670. Traffic entering via Long Street were not allowed to exit at I-670. This arrangement provided a longer weaving section between the I-70 on-ramp

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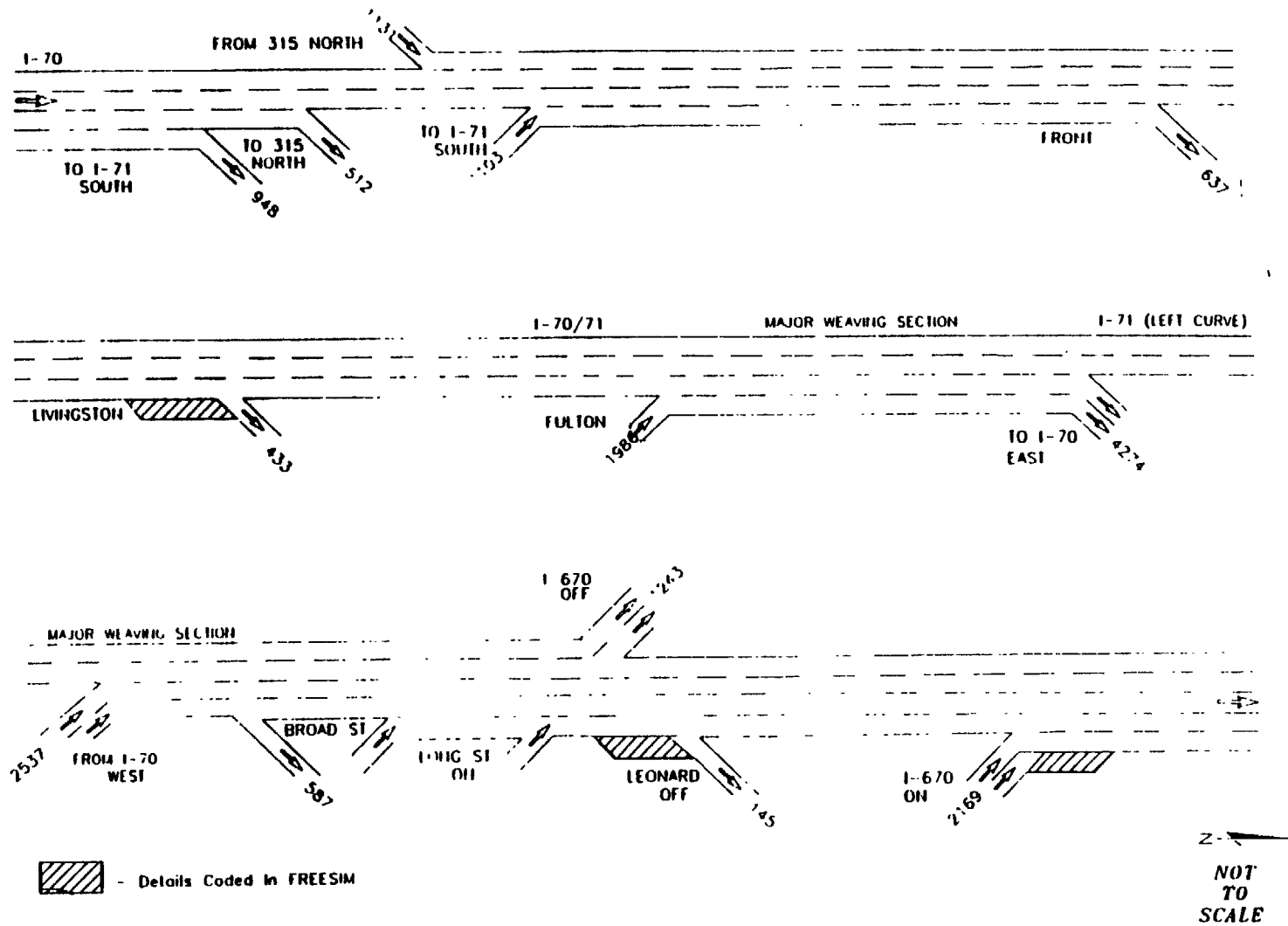
Figure 51. Columbus, Ohio I-71: I-670 exit relocation alternative future p.m. peak hour ramp volumes.

and the l-670 off-ramp and allowed more efficient use of all lanes available in the section.

- Alternative #2, :I-670 Exlt Elimination" (see figure 52) also focused on reducing theweaving between the l-70 on-ramp and the l-670 off-ramp. In this case, the left-hand exit to l-670 was closed. A new off-ramp was added on the left side at Broad Street. This was only to be used by mainline traffic. Traffic from the l-70 (westbound) on-ramp headed for downtown used the existing right-hand Broad Street off-ramp. Current traffic exiting at l-670 was redistributed according to the following assumptions:

  - Vehides destined to areas west of Route 315 will use l-71 (southbound) and Route 315 (northbound) and will not enter the study area.

  - Vehicles headed to the area served by l-670 in the north will not exit via the current l-670 off-ramp, but via l-71 north and the exit ramps located north of l-670.

  In addition to the ramp modifications noted above, several lengths of additional mainline lanes are also added to the section of freeway downstream of the l-70 (westbound) on-ramp.

In each case, the alternatives were developed with a view to substantially improving future levels of traffic operation while at the same time minimizing the amount of land-taking and building demolition required. For this reason, other options that might potentially provide better lane balance were considered but discarded. It was also considered that purely operational controls (e.g., restrictions on certain weaving movements), while providing probable short-term improvements, would not represent a viable long-term solution.

Evaluation of Alternatives:

Figure 53 summarizes the results of the FREQ and FREFLO runs for the existing (base) condition and each of the alternatives. For the base condition, runs were made using both current traffic and a projected 10-percent traffic growth. For the two alternatives, runs were made only for the W-percent traffic growth condition.

FREQ and FREFLO produced somewhat diierent results. Both indicated a significant decrease in average speed for the base condition as traffic increased, with an equivalent increase in delay. The impact was substantially higher, however, for FREQ than FREFLO.

Comparison of traffic performance under the two alternatives indicated conflicting results for alternative #1, 'l-670 Exit Relocation', with FREQ indicating an improvement and FREFLO indicating a deterioration in speeds and delays both models indicated a slight increase in total vehicle miles of traffic processed. For alternative #2, 'I-670 Exit Elimination, both models showed a deterioration in performance, with the change being more marked for FREFLO than FREQ.

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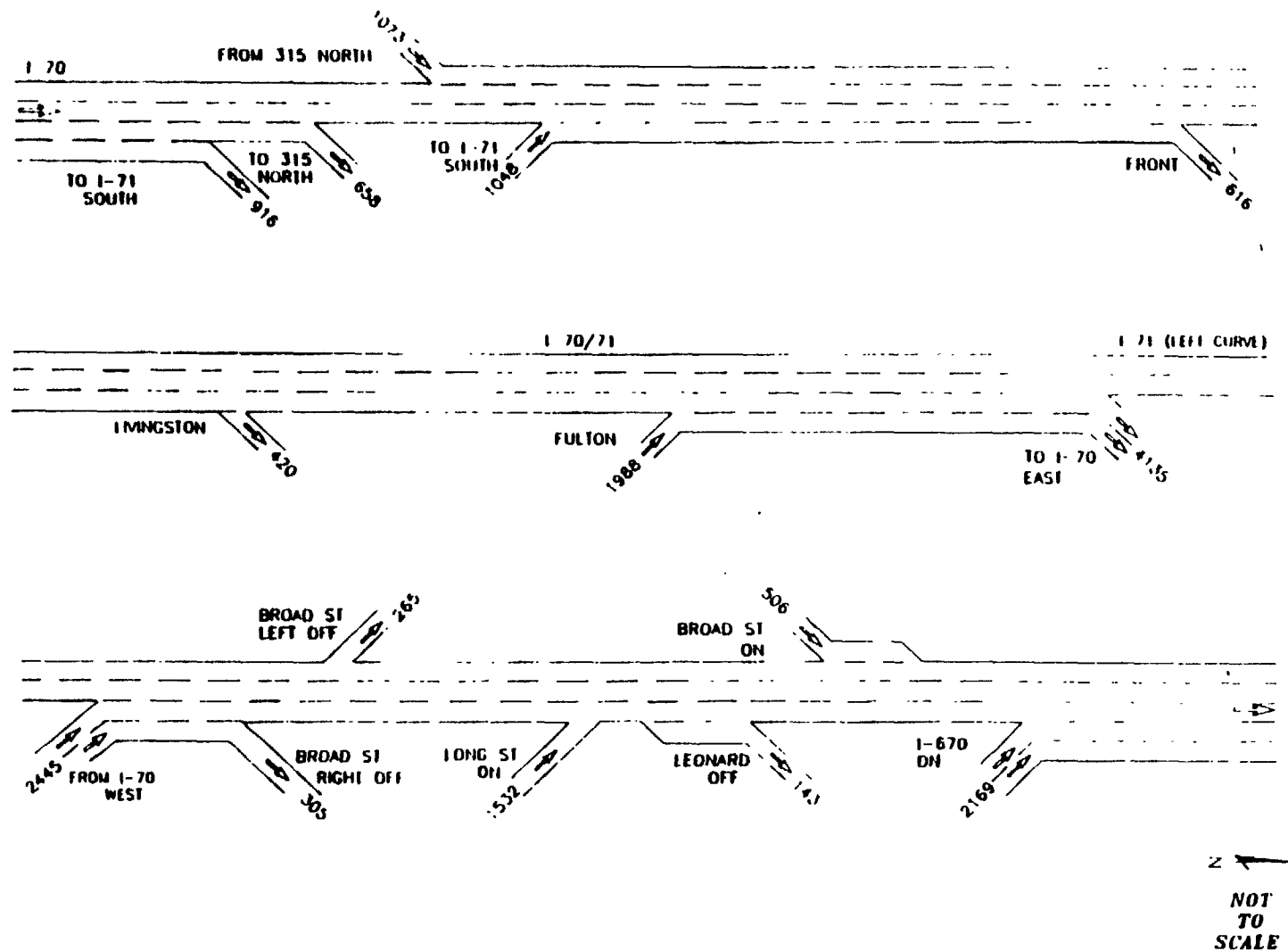
Figure 52. Columbus, Ohio I-71: I-670 exit elimination alternative future p.m. peak hour ramp volumes.

COLUMBUS 1-71 ALTERNATIVE ANALYSIS

2:00 - 6:00 P.M

		AVE. FW SPEED mi/h	MIN. SPEED mi/h	FW. TRAVEL TIME VEH. HRS.	ON-RAMP DELAYS VEH. HRS	TOT. TRAVEL TIME VEH. HRS	DISTANCE TRAVELLED VEH. MI	TRAVELLED PASS. M.	OVERALL AVE. SPEED mi/h	MAX. V/C	FUEL USED GAL.	CO EMISS. KG.
YEAR 1989												
BASE CONDITION	FREQ	54.0	26.0	1.473	7	1,480	79,593	100,287	53.8	1.00	4,781	1,366
	FREFLO	54.6	31.2	1,437	n/a	n/a	76,505	100,487	n/a	n/a	n/a	n/a
10% GROWTH												
NO BUILD	With Weaving	FREQ	28.8	7.0	2,928	361	3,289	84,388	106,329	25.7	1.00	5,789	2,916
	FREFLO	38.0	11.9	2,227	n/a	n/a	84,507	108,343	n/a	n/a	n/a	n/a
	WO Weaving	FREQ	34.8	7.0	2,503	27	2,530	06,990	109,618	34.4	0.93	5,680	1,842
	FREFLO	35.1	7.3	2,404	n/a	n/a	86,000	110.080	n/a	n/a	n/a	n/a
1-670 EXIT RELOCATION	FREQ	34.1	10.0	2,587	450	3,037	88,183	111,111	29.0	0.97	6,512	3,907
	FREFLO	31.7	10.0	2,706	n/a	n/a	85,817	110,011	n/a	n/a	n/a	n/a
1-670 EXIT ELIMINATION	FREQ	27.4	4.0	3,051	211	3,265	83.527	105,244	25.6	1.00	5,997	2,907
	FREFLO	29.7	1.9	2,709	n/a	n/a	80,503	103,205	n/a	n/a	n/a	n/a

1 mi/h = 1.61 km/h

Note: n/a = not ● available

Figure 53. Columbus, Ohio case study: summary of FREQ and FREFLO results.

The FRESIM model was used to examine each of the alternatives and also the base condition in more detail. In the case of the base condition, runs were made using existing traffic and both a 10- and a 20-percent increase in all input flows. Each of the two alternatives were simulated using both a 10- and a 20-percent increase in traffic. All FRESIM runs were made for the entire study section.

The results of these analyses are summarized in figure 54. As might be expected, average speeds for the base condition fall off rapidly, and delay increases as the volume of traffic increased. Alternative #1, "I-670 Exit Relocation," appeared to produce significant improvement in operations for both the 10- and 20-percent increase in traffic levels, with the deterioration in performance as traffic increased being less dramatic than for the no-build base condition. The results for alternative #2, I-670 Exit Elimination,' were less clear cut. In this case, average speeds for a lo-percent increase in traffic were less than for the no-build case, but for a 20-percent increase were slightly higher. For both the 10- and 20-percent traffic growth scenarios, the level of performance obtained with alternative #2 was poorer than that for alternative #1.

Lessons Learned:

Recommended Improvement: All of the models tended to indicate that under future traffic conditions, alternative #1, involving the relocation of the I-670 exit, and resulting in the lengthening of the weaving section between the I-70 on-ramp and the I-670 off-ramp, when coupled with selected widening of the mainline in the same critical weaving section, yielded the best results. The finding was probably dearest in the case of the FRESIM analyses.

It would be desirable to further refine the options tested here, and to comblne them with additional geometric and operational modifications.

The Analysis Process: All of the points noted earlier apply also in this case, concerning, such issues as:

- Need to compare results on the basis of comparable VMT's.
- Constraints imposed by lack of field data
- Too narrow a study area
- Need for better data for calibration, particularly of FRESIM.
- No attempt to conduct a full-scale cost-beneftt analysis.

In this case, the FRESIM model runs illustrated clearly the value of evaluating the performance of alternative improvement schemes using several levels of future traffic – in this case, 10- and 2O-percent growth, rather than a single future projection.

By far the most significant analytical conclusions, however, to be drawn from this case study deal with the treatment of weaving behavior. Both FREQ and FREFLO depended on the procedures defined in the HCS to estimate the impact of weaving on capacity and hence traffic operations. Both models appeared to yield results that were hard to interpret and that may have underestimated the capacity of complex weaving sections.

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Alternative	Total VMT (miles)	Total VHT (hours)	Average speed (mi/h)	Delay Time (min/veh-mi)
Base Case				
Existing Traffic	35,574	658.5	54.0	0.14
10% Increase In Traffic	38,670	828.6	46.7	0.31
20% Increase in Traffic	39,977	1,186.4	33.7	0.79
Exit Relocation				
10% Increase in Traffic	45,382	852.5	53.2	0.12
20% Increase in Traffic	48,720	949.9	51.3	0.16
Exit Elimination				
10% Increase In Traffic	42,193	1,013.9	41.6	0.42
20% Increase In Traffic	44,983	1,149.9	39.1	0.51

1 mi = 1.61 km
1 ml/h= 1.61 km/h

Figure 54. Columbus, Ohio, case study: summary of FRESIM results

The FRESIM model, while it appeared to generate a very large number of lane changes under certain traffic conditions and possibly a greater number than actually occurred in the field, appeared to better replicate the actual operations of complex weaving sections of the type considered in this-case study.

It is probably fair to say, however, that the overall issue of weaving behavior, and its appropriate treatment in all of the models tested requires further attention.

One other point should also be noted. The second of the two alternatives tested involved substantial changes to ramp locations, with consequent impact on the distribution of traffic. This latter impact was estimated using some simple decision rules. It would have been helpful in this process if the models had the ability to deal with pre-specified origins and destinations. This ability exists partially in some of the models, but not in all of them.

CASE STUDY #5: MINNEAPOLIS, MINNESOTA

I-494 (Eastbound) Between Prairie Center Drive and TH 4

Study Location:

The final case study focused on an 1 1-mi (17.7 km) section of I-494 (eastbound) between Prairie Center Drive and TH 5 south of Minneapolis, Minnesota. Figure 55 illustrates the study location.

Fiiure 56 illustrates the existing lane configuration. The initial 4-mi of the eastbound study section are two lanes wide; the remaining 7-mi (11.3 km) are three lanes wide. There are nine simple and four complex interchanges within the latter 7-mi (11.3 km) segment, with resultant close ramp spacings. At the time of the analysis several of the entrance ramps were metered, including the ramp from eastbound I-494 to I-35W (southbound).

The study section carried ADT ranging from 115,006 to 145,000 vehicles/d, with peak period flows of roughly 6,100 veh/h in the morning peak period and 6,650 in the evening peak period. The segment operated at capacity for approximately 2-h/d, with substantial complex weaving and congestion. Truck traffic amounted to approximately 5-percent of the traffic stream.

Application of Models:

The HCS modules were again used to estimate the capacity of each subsection of the 11 -mi (17.7 km) study section and help assess lane requirements for alternative improvement schemes. The two macroscopic models, FREQ and FREFLO were used to simulate the entire study section for a 4-h period from 3:00 PM to 7:00 PM spanning the evening peak period. FRESIM was used to examine in detail a shorter section between CR 28 and Portland.
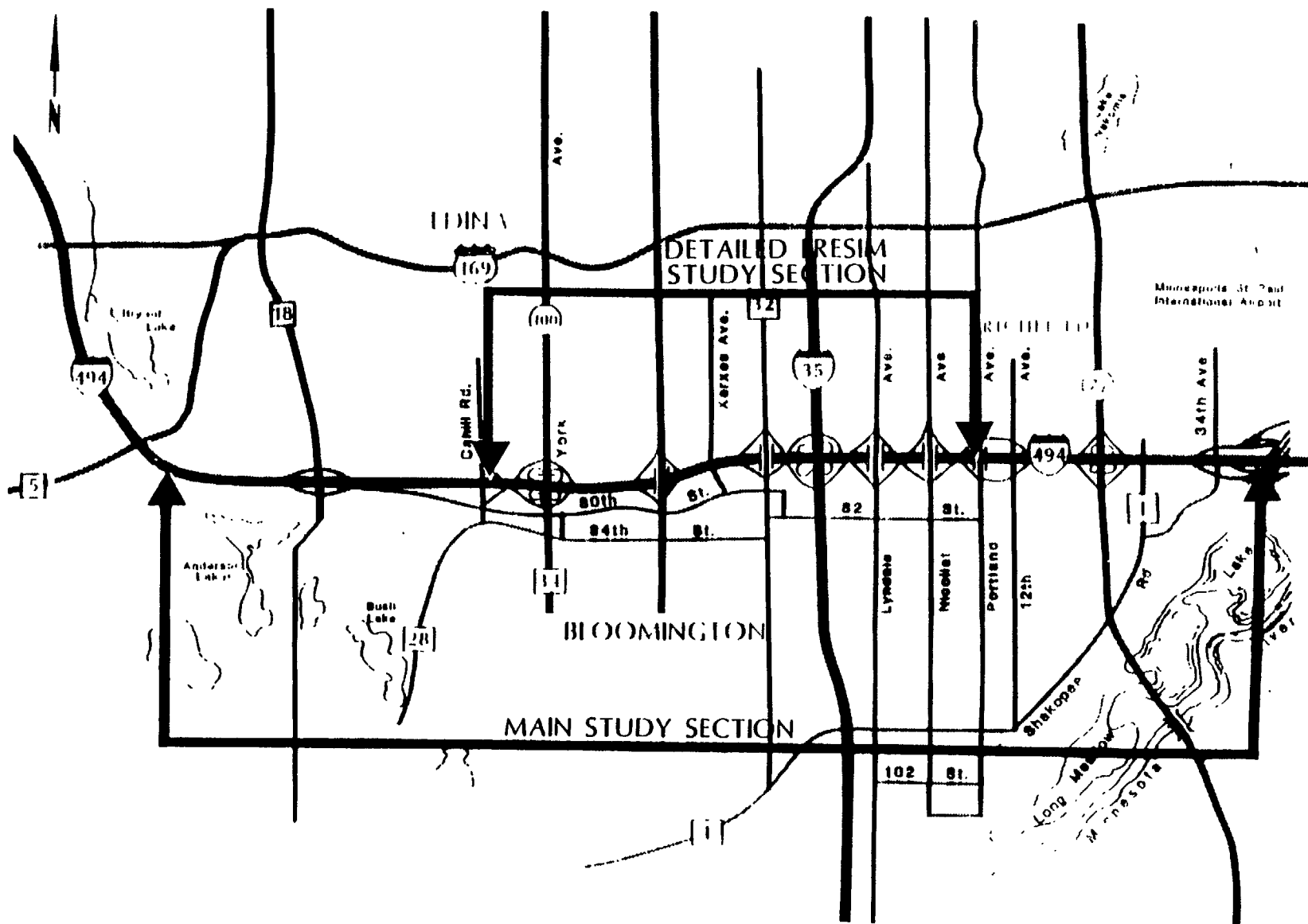
Figure 55. Minneapolis, MN: I-494 study location.

FREESIM STUDY SECTION

PRARIE
CENTER

RTE 169

CR 2B

III 100 SB

III 100 NB

FREESIM STUDY SECTION

FRANCE SB

FRANCE S

PENN

I 35W SB

I 35W NB

FREESIM STUDY SECTION

LYNDALE

NICOLLET

PORTLAND   I III

III 7   B

TH 77 NB

24TH

34TH

TH 5
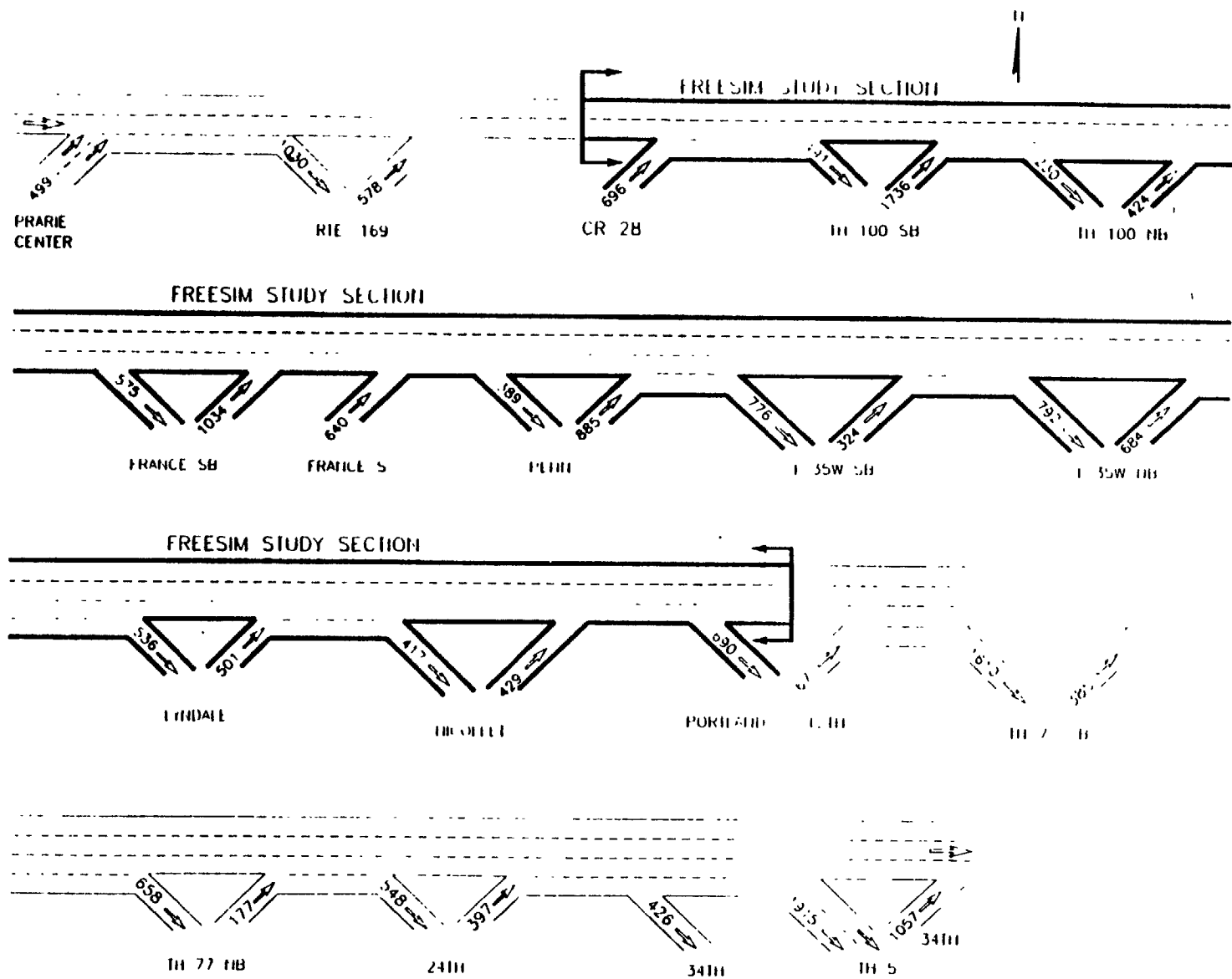
Figure 56. Minneapolis I-494: existing lane configuration, 1989 p.m. peak hour ramp volumes.

involving very close ramp spacing and significant weaving. The section involved is illustrated in figure 55.

Data on geometry, existing (1969) traffic flows and controls were provided by the Minnesota Department of Transportation (MinnDOT). A limited number of moving-car travel-time runs were made throughout the study section to obtain estimates of actual traffic speeds. Preliminary traffic forecasts supplied by MinnDOT indicated an average growth in traffic of 39-percent by the year 2010. This growth factor was applied uniformly to all flow in testing future-year alternatives.

Model Calibration:

In addition to the comparisons of model output and field observations of volume and speed by subsection, calibration of the FREQ and FREFLO models focused particularly on the impact of weaving on subsection capacity.

Initial model runs were conducted using a basic capacity of 2,000 pcphpl modified by an assumed 5-percent of trucks to yield a basic segment capacity of 1,900 vehicles/lane/hour. FREQ includes a routine based on the 1965 HCM that estimates the effect of weaving on capacity. Using this routine yielded substantially lower estimates of capacity, and hence substantially higher estimates of delay than were observed in the field. Unfortunately, at the time the case study was undertaken, no sat&factory procedures existed for estimating the impact of weaving on capacity more accurately.   In an attempt to address this issue, the weaving algorithm in the FREQ model was used to conduct a sensitivity analysis of the relationship between weaving section capacity reduction, weaving volume, and weaving section length.

The results of this analysis are described in detailed in the Model Calibration Report for this case study (report # V.2 in figure 24). They suggested that the FREQ routines based on the 1965 HCM generally overestimated the effect of weaving on capacity by approximately a factor of two. That is, a FREQ-generated weaving section capacity reduction of 1,000 veh/h should more accurately be depicted as a reduction of 500 veh/h.

The modified weaving section capacities were input to runs of both FREQ and FREFLO for existing conditions, and were found to yield speed and volume output much closer to those observed In the field. However, the FREFLO model still yielded speeds substantially higher , than those observed from the travel time runs and further capacity adjustments were needed to produce a final calibrated model.

One additional issue that presented itself was the ability of FREQ and FRESIM to simulate the effect of the I-35W ramp metering on operations on I-494. Neither model had the ability to handle this effectively. The reasons are again discussed in detail in the case study Model Calibration Report The only way in which queuing patterns on I-494 due to the ramp metering operation could realistically be replicated was to adjust the capacity of the section of I-494 approaching the off-ramp to I-35W to a level of 6,400 veh/h.

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The FRESIM model was again run for existing conditions using the standard set of default values for the calibration parameters. Comparison of model output to field data for volumes and speeds by subsection indicated an acceptable level of comparability, and did not provide any basis for changing the values of any specific parameter. It should again be noted, however, that there was no field data available that addressed the values of these parameters directly.

FRESIM models both lane changing and ramp-metering directly, so that the issues noted above for the calibration of FREQ and FREFLO were not directly applicable. It was noted, however, that while the model yielded reasonably accurate representations of the pattern of existing congestion, it tended to generated a very high number of lane-changes within the mainline section, and appeared to somewhat underestimate delay on the ramp from I-494 to I-45W.

Figure 57 illustrates one of the set of speed profiles used in the calibration process comparing the field observations derived from moving-car travel-time runs with runs of each model. The data were for the period of 4:30 PM to 4:45 PM and cover the entire study section.

Evaluation of Existing Conditions and Development of Alternatives:

All of the simulation analyses Indicated a serious bottleneck condition at the I-35W interchange, with significant congestion developing at that point and spilling back upstream. Additional problems were also identified In the speed and density contour plots at the TH 100 and TH 77 interchanges, and in the case of the FRESIM runs at the France Street interchange. The cause of these operational problems was a combination of heavy traffic and significant weaving movements associated with the I-35W exit and adjacent, closely spaced entrance and exit ramps.

Three basic improvement alternatives were developed:

- **Alternative #1, "Ramp Metering,"** attempted to Improve operations at minimum cost No changes were made to the existing mainline cross section. All on-ramps except those at TH 100, I-35W, and TH 77 were metered.

- **Alternative #2, "HOV Alternative,"** involved the addition of an HOV lane to the left-hand side of the traveled way throughout the study section.

- **Alternative #3, 'TSM Alternative,"** focused on a comprehensive set of improvements designed to provide a highquality freeway environment. It included lane additions and interchange modifications designed to provide lane balance at all merge and diverge points. Three basic lanes were maintained downstream of Prairie Center Drive where current congestion was heaviest. Several on-ramps were dosed, one new on-ramp was added, and the I-35W interchange was re-constructed to provide for single entrance and exit points.

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I - 494 EXISTING CONDITIONS (1989)
4:30 - 4:45 P.M.
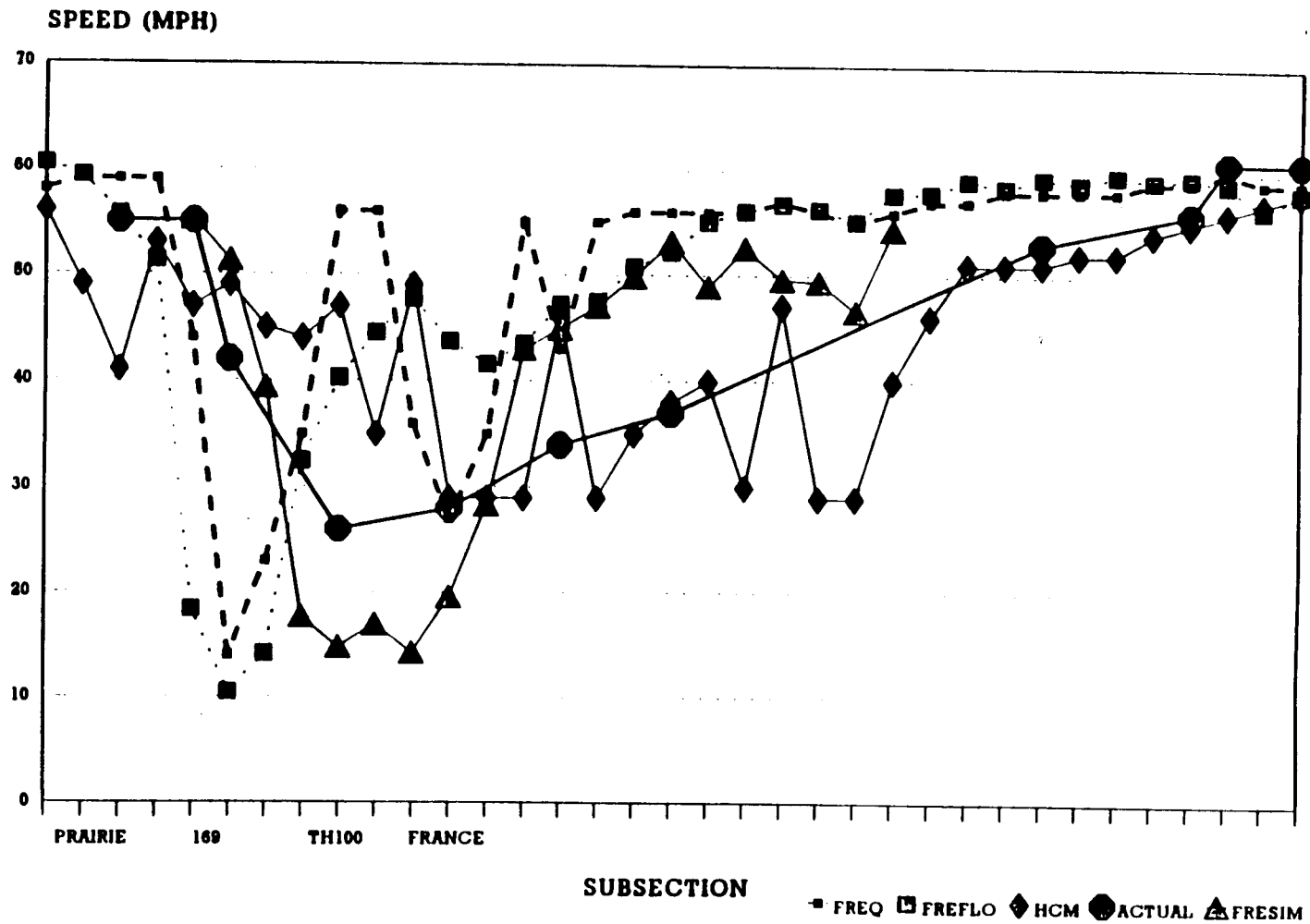
Figure 57. Minneapolis I-494: speed profiles for existing conditions.

The detailed lane configuration for alternatives #2 and #3 are illustrated in Figures 58 and 59 respectively. Figure 60 illustrates the lane configuration and subsection boundaries for the detailed FRESIM study section.

Evaluation of Alternatives:

The FREQ and FREFLO models were used to evaluate each of the three alternative improvement scenarios described above. FRESIM was used to evaluate the TSM alternative (alternative #3), plus two modifications to that alternative based on adding an extra lane between CR 38 and TH 100 (see figure 61) and implementing fixed-rate, clock-time metering at selected entrance ramps.

In the case of the FREQ and FREFLO analyses, only one level of future traffic was analyzed, reflecting a 39-percent growth over existing conditions. The FRESIM model was used to evaluate performance for the improvement schemes tested for traffic growth levels of 12-percent, 25-percent and 39-percent.

Figure 61 summarizes the results of the FREQ and FREFLO analyses. The two models yielded generally similar results. However, due to the large projected increase in demand, all travel could not be accommodated In the simulation period. It would have virtually been impossible to extend the simulation period long enough to accommodate the demand in the no-build condition. One option would have been to add one or two time slices with zero demand to allow the queues to dissipate. Factoring to equivalent VMT would at least equalize the comparisons.

Both showed a marked deterioration In performance for the no-build case with 39-percent traffic growth, with FREFLO yielding somewhat poorer performance than FREQ. The FREQ runs suggested that the introduction of ramp metering with no other changes (alternative #1) would return a performance of the freeway close to that for the existing condition (not including the additional ramp delay); the improvement detected by FREFLO was somewhat less significant, but still marked.

According to the FREQ model alternative #1 also produced a performance substantially better than either of the other two alternatives when measured in terms of overage speeds, total vehicle miles traveled, and average delay FREFLO yielded slightly dirrerent results, suggesting that alternative #1 was better than alternative #2, but marginally less effective or , accurate than alternative #3.

A detailed analysis of these findings is again given in the Case Study Alternative *Analysis Report* (report # V.3 in figure 24).

The FRESIM runs were somewhat less wndusive (see figure 62). When traffic was increased by 39-percent, the model aborted for the base case, the TSM Alternative (alternative #2), and for the modified TSM Alternative without metering. The problem was caused by excessive traffic demand, resulting in the number of vehicles within the modeled section exceeding the capacity of the model's vehicle array.
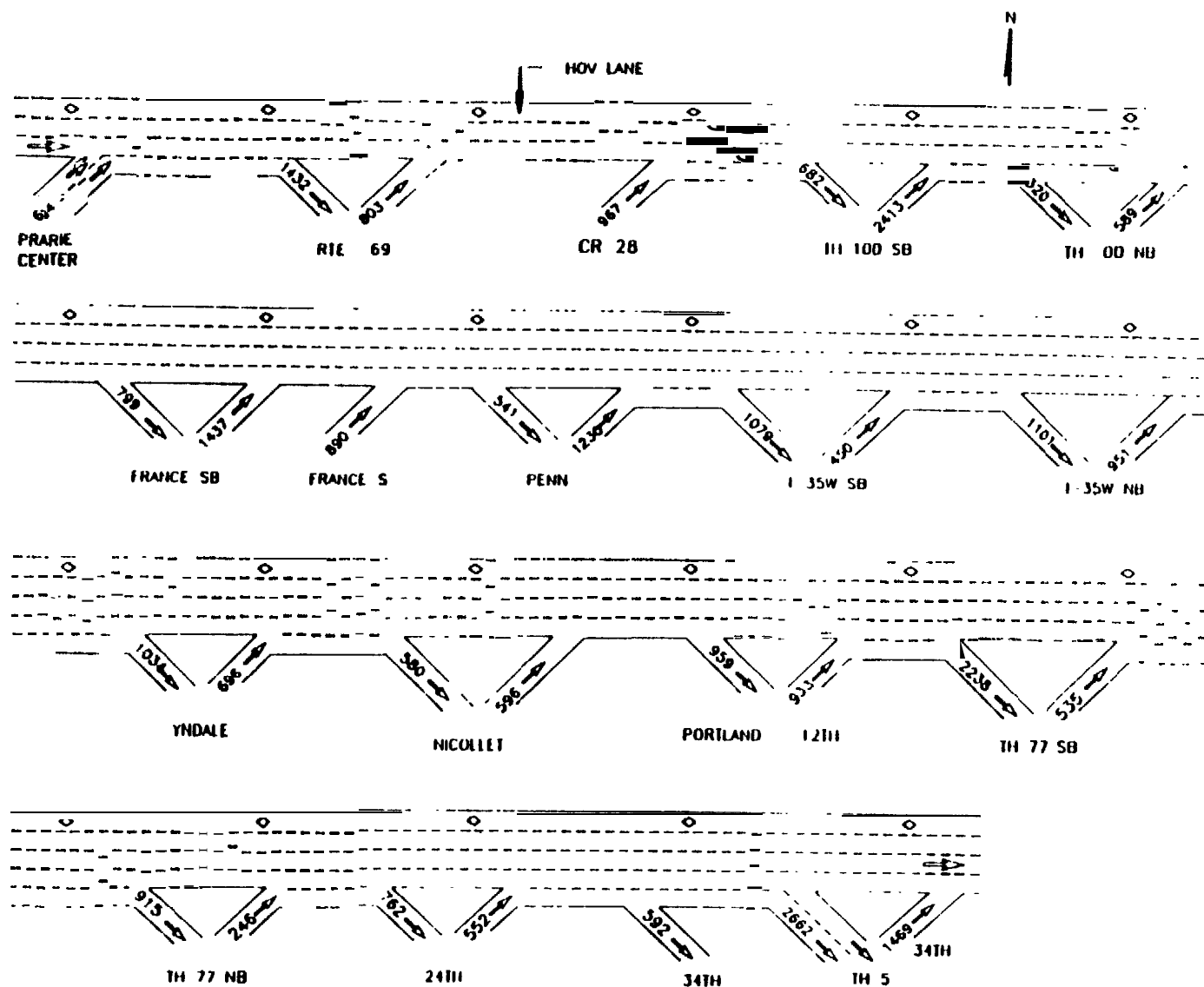
Figure 58. Minneapolis I-494: HOV alternative future p.m. peak hour ramp volumes.
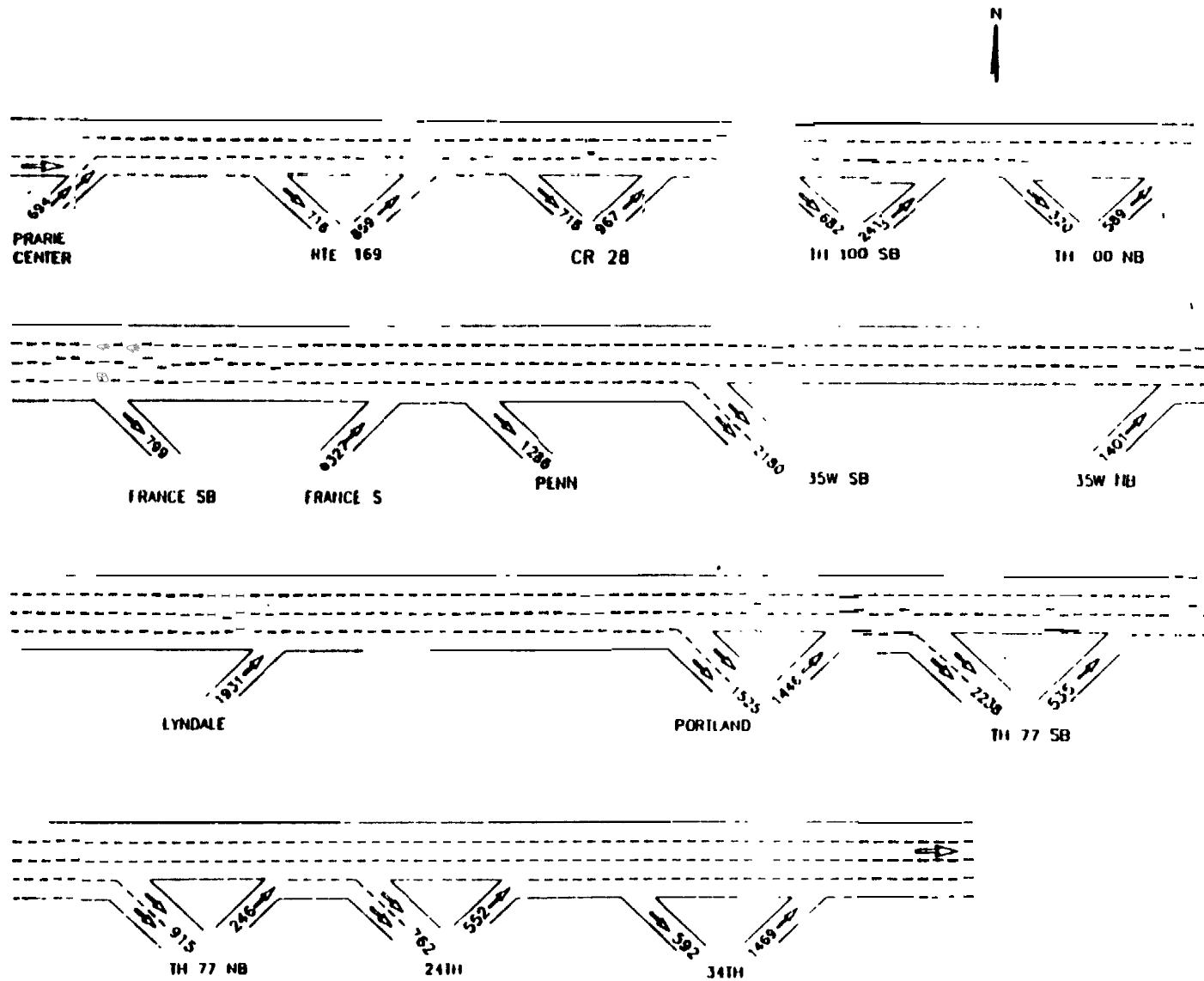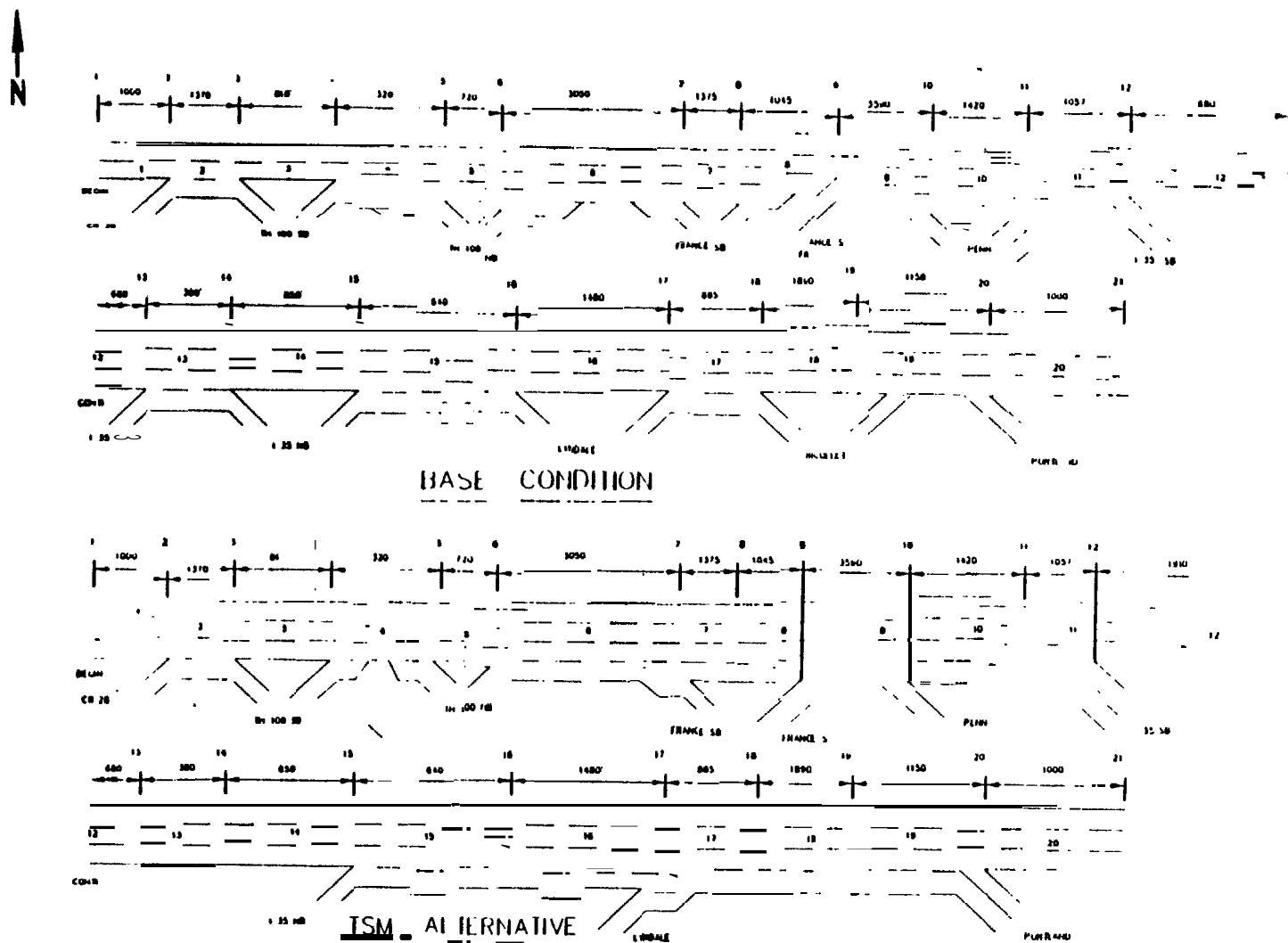
N

PRARIE
CENTER   HTE 169   CR 28   III 100 SB   TH 00 NB

FRANCE SB   FRANCE S   PENN   JSW SB   JSW NB

LYNDALE   PORTLAND   TH 77 SB

TH 77 NB   24TH   34TH

Figure 59: Minneapolis I-494: TSM alternative future p.m. peak hour ramp volumes.

BASE CONDITION

ISM ALTERNATIVE

1 ft. = 0.305 m

Figure 60. Minneapolis I-494: lane configuration for FRESIM alternatives.

MINNEAPOLIS I-494 ALTERNATIVE ANALYSIS
SUMMARY OF FREEWAY PERFORMANCE

3:00 - 7:00 PM

		AVE. FWY SPEED (mi/h)	MIN. SPEED (mi/h)	FW. TRAVEL TIME VEH.HRS.	ON-RAMP DELAYS VEH.HRS	TOT. TRAVEL TIME VEH.HRS	DISTANCE TRAVELLED .... VEH.M.	TRAVELLED PASS.MI.	OVERALL AVE. SPEED (mi/h)	MAX. V/C	FUEL USED GAL.	CO EMISS. KG.
YEAR 1989												
BASE CONDITION	FREQ	37.8	8.0	4,333	2	4,335	163,861	206,465	37.8	1.00	10,250	3,756
	FREFLO	34.8	10.1	4,677	n/a	n/a	162,844	208,766	n/a	n/a	n/a	n/a
39% GROWTH												
No Build	FREQ	24.3	4.0	7,016	19,269	26,285	170,517	213,433	6.5	1.00	23,104	28,324
	FREFLO	16.7	0.5	8,960	n/a	n/a	149,424	192,459	n/a	n/a	n/a	n/a
Ramp Metering Alternative	FREQ	36.2	10.0	5,016	15,935	20,951	181,451	253,220	8.7	1.00	20,621	22,822
	FREFLO	27.9	8.2	6,192	n/a	n/a	172,727	221,954	n/a	n/a	n/a	n/a
HOV Alternative	FREQ	23.7	1.0	7,494	6,186	13,680	177,339	235,329	13.0	1.00	16,312	13,054
	FREFLO	20.3	3.3	8,621	n/a	n/a	175,350	247,964	n/a	n/a	n/a	n/a
TSM Alternative	FREQ	29.1	5.0	5,995	14,773	20,768	174,232	219,532	8.4	1.00	21,253	22,053
	FREFLO	31.1	8.0	5,965	n/a	n/a	185,599	238,310	n/a	n/a	n/a	n/a

Notes: n/a = not available
     Results for the HOV Alternative represent combined results of both priority and non-priority lanes.

1 mi/h = 1.61 km/h

Figure 61. Minneapolis I-494: summary of FREQ and FREFLO results.

Alternative	Total VMT (miles)	Total VHT (hours)	Overall Avg. Speed (mi/h)	Delay Time (min/veh-mi)
Existing Traffic				
Base Case	02,703	2,350	35.2	0.68
39% Increase In Traffic				
Base Case	N/A	N/A	N/A	N/A
TSM Alternative	N/A	N/A	N/A	N/A
Modified TSM Alternative				
39% Growth	N/A	N/A	N/A	N/A
25% Growth	N/A	N/A	N/A	N/A
12% Growth	N/A	N/A	N/A	N/A
Modified TSM Alternative with Ramp Metering				
39% Growth	77,619	1,636	47.4	0.15
25% Growth	68,248	1,445	47.2	0.16
12% Growth	66,950	1,366	49.0	0.10

Note: N/A = not applicable;
FRESIM simulation aborted due to excessive demand and queues that backed up all the way to the beginning of the study section.

Figure 62. Minneapolis summary of FRESIM results.

For the modified TSM Alternative with metering, speeds were generated that were 10 mi/h (16.1 KM/H) higher than those predicted by FREQ and FREFLO, that performance tailing off as volume levels increased.

Lessons Learned:

Recommended Improvement: The results of the FREQ and FREFLO model runs in this case are somewhat surprising. On the surface, they indicate that ramp metering with no additional improvements could provide benefits greater than those to be obtained either via significant improvements to the geometry of the study section or through the introduction of an additional HOV lane. However, the ramp metering options "hide' some of the delay in ramp queues that are not able to dissipate by the end of the simulation period. It is expected that the major geometric improvements reflected in alternative #3 would yield at least equal or greater benefits, once these delays are accounted for. Thus, the importance of dealing with the simulation time period and of equivalent VMT cannot be over emphasized.

It was hoped that detailed analysis of the most congested portion of the study section using the FRESIM model would shed some light on the issue. Unfortunately, however, as noted above, the volume of traffic was so high that the majority of the model runs aborted, and no conclusive results were obtained. It is possible that the growth projections are unrealistically high for the geometric conditions examined.

The Analysis Process: All of the comments made in the preceding case study discussions apply again here. In addition, three other significant points should be noted:

- The two macroscopic models, FREQ and FREFLO, do not have the capacity to deal realistically with a metered freeway-to-freeway connector. FRESIM can model this situation.

- Neither of the two macroscopic models can realistically represent performance under heavy weaving conditions. FRESIM can do so, but it appears that the model may exaggerate the amount of lane-changing that occurs.

- FRESIM is limited in its ability to simulate long sections of congested freeway by the capacity of the model's vehicle array. The problem could have been partially circumvented by extending the simulation time-step from 1 to 2 seconds, something that resources did not permit in this case.

A CONCLUDING COMMENT

The five Case Studies that have been briefly described in this final chapter provided a very useful test-bed for evaluating both the ease with which the models covered in this research could be applied, and also the degree to which they appeared to realistically represent reality. Some of the major conclusions emerging from each case study have been highlighted in this chapter.

More important than these Case-Study-specific observations, however, are the broader conclusions that were drawn from the research team's experiences with the models. These formed the basis for the discussion and recommendations made in chapters 2, 4, and 6 of this report.

APPENDIX A. CONSIDERATIONS IN IDENTIFYING CAUSES
OF FREEWAY MOBILITY PROBLEMS

This appendix supports the material in chapter 5. It should be used in conjunction with table 5 to more dearly determine possible causes associated with congestion problems and to assist in selecting appropriate strategies for testing. The discussion is keyed to the numerical code for each cause listed in table 5. Additional references providing more information on strategies for mitigating freeway congestion problems are provided at the end of this report.

1.1.1 and 1.2.1: Ramp Merge/Diverge - Inadequate Speed Change Lane Length

Description of Cause:

An inadequate speed change lane (SCL) length reduces the level of service and capacity of the merge/diverge. When inadequate distance exists on the ramp for entering vehicles to accelerate to near mainline speeds before entering the mainline, the ramp vehicles will generally enter at speeds attained at the end of the SCL, rather than abort entry.   In the case of low-speed entry or aborted entry, the mainline flow is usually affected and braking occurs. With sufficient mainline volume, but not necessarily near- normal merge capacity, the discontinuities caused by the braking can create shock waves that result in a breakdown upstream on the freeway.

Short SCL's at exits from freeways result in inadequate distances to decelerate comfortably to the controlling condition on the ramp. As a result, the driver will slow on the mainline before exiting. Mainline flow is then affected and braking occurs. With sufficient volume, but not necessarily at normal diverge capacity, the discontinuities caused by the braking can create shock waves that result in a breakdown upstream on the freeway.

General Considerations:

The problem can be identified through several measures that may exist even though volumes at the merge would normally suggest a higher level of service:

- Acceleration noise significantly in excess of what occurs on the mainline under free-flow conditions between ramps.

- Severe braking along the approach to the merge/diverge.

- The beginning of congestion along the approach to the merge/diverge.

- Presence of queues upstream of the merge/diverge, but not downstream.

- Speed reduction through the merge/diverge.

1.1.2 and 1.2.2 - Ramp Merge/Diverge - Inappropriate Design Features

Description of Cause:

Merging/Diverging - end areas that involve:

- Sharp mainline and/or ramp curvatures.

- Sight restrictions.

- Narrow lanes and/or shoulders.

- Mainline and ramp curvatures in opposite directions.

- Ramp curvature that extends beyond the merging end into the acceleration area.

These will, either individually or in combination, result in poor merge operation with the possibility of reduced merge capacity. The operational impact is usually indicated by the following attributes, even under volumes at the merge that normally are associated with a higher level of service:

- Low speed direct entry to/exit from. the mainline without use of the speed change lane.

- Acceleration noise significantly in excess of what occurs on the mainline under free-flow conditions between ramps.

- Severe braking along the approach to the merge/diverge.

- Presence of queues upstream of the merge/diverge, but not downstream.

- Speed reduction through the merge/diverge.

- Unusually hlgh lane-changing on the mainline in advance of the merge/diverge.

General Considerations:

Many early designs of ramp terminals at merges resulted in conditions that negatively affected the operation at merge and diverge points. These often result from a combination of inappropriate design features at the merging and diverging ends of the kind listed above. While these features usually result in an operational impact similar to those resulting from inadequate speed change lane lengths, the latter is dealt with as an independent cause.

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The placement of a relatively sharp curvature along a ramp at the merging/diverging end will result in a low speed at the beginning of the acceleration lane for a merge and slowing of exiting vehicles on the mainline approaching the diverge. Even if the speed change lane (SCL) length is adequate on an entrance ramp, there may be a tendency for the driver of a ramp vehicle to enter before adequate speed is reached, because the driver is faced with a possible loss of headway opportunity for entry. If the ramp curvature extends beyond the merging or diverging end, and physical separation is not provided along the acceleration/deceleration lane, this will encourage early entry by ramp vehicle drivers at entrance ramps and slowing on the mainline for exit ramps. When the ramp and mainline are curving sharply in opposite directions at the merge, the super-elevation requirements result in undesirable crown-line crossover rates, or inadequate super-elevation rates through the transition areas. This can violate driver expectancy, resulting in erratic maneuvers and momentary loss of control of the vehicle.

These inappropriate designs can cause the entire upstream section of the corridor to be affected because they result in bottlenecks. Their improvement, therefore, may have a far reaching impact within the corridor.

1.1.3 and 1.2.3: Ramp Merge/Diverge - Demand Too Large

Description of Cause:

When the amount of traffic wanting to enter or exit the freeway exceeds the capability of the merge/diverge area to accommodate it efficiently, the problem is said to be one of excessive demand. Heavy demand on a ramp, on the mainline, or both, may result in poor operations. At an interchange, problems related to large demands may occur downstream of a merge or upstream of a diverge, on the ramp itself, or at the ramp terminus with the intersecting facility. Problems tend to be most prevalent during peak hours.

The following indicators can be used to determine if the problem is one of excessive demand at a ramp merge/diverge:

- Slow downs or queues on the mainline upstream of a merge area may occur when volumes are high. These would typically be most common in lane 1 (adjacent to the ramp lane), although adjacent lanes may be affected too.

- Through traffic will shift away from the lanes affected by the merging/dierging traffic. This results in unequal lane utilization on the mainline.

- Lane changing may become intense in the vicinity of the merge/diverge as drivers attempt to avoid conflicts.

- Queues or slow downs on the ramp proper at entrances and exits. Stop and go operations may result for entering traffic in merging areas.

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- Limited gaps for merging vehicles. Headways are uniform, but gaps are short. Entering traffic and traffic in lane 1 will adjust speed frequently to avoid conflicts.

- Shoulder riding by ramp traffic downstream of a merge and upstream of a diverge.

- At a diverge, slow downs or ramp queues may extend back into the deceleration area or into the mainline lanes.

- Diversion to other surface streets, parallel facilities, or upstream and downstream ramps.

General Considerations:

Ramp geometrics and controls, plus the design of the mainline, may affect the degree to which the above conditions occur. Inadequate capacity on an exit ramp or the control at its terminal with the cross road can have a substantial impact on the mainline and speed change lane area. Surface facilities may be adversely affected by poor operation of a merge area on the mainline. One must address not just the point specific problems, but also consider the possible impact on other streets and highways in the corridor as a result of taking, or not taking, corrective action.

The availability of right-of-way (ROW) and impact on surrounding land uses (if additional lanes are added) need to be assessed. Drainage, dear zone requirements, and signing changes may be needed If the cross section is increased. The length and location of an added lane has to be coordinated with adjacent interchanges to provide lane balance. The time for completion of the project, the traffic control plan during construction, and project costs are important factors, too. Also, the extent that the future volume estimates reflect the use and effects of travel demand management strategies should be determined.

1.1.4 and 1.2.4: Ramp Merge/Diverge - Left-Hand Ramp

Description of Cause:

Operational problems occur at left-hand ramps because exiting and entering maneuvers are made to and from the left lane, which is usually operating at the highest average speed. In addition, driver expectancies are violated because left-hand ramps are not normally anticipated. For the exit situation, driver expectancy violation may cause erratic maneuvers prior to the diverge.   It may also cause severe braking when a through vehicle in the left lane is trailing an exiting vehicle that slows prior to exiting. For the entering situation, the mainline vehicle may not be anticipating an entering vehicle. The entering vehicle may

have difficulty attaining the high operating speed in the left lane. The more aggressive driving that generally occurs in the left lane may make it more difficult for an entering vehicle to merge.

The problem can be identified, therefore, by noting the number and nature of erratic maneuvers occurring prior to and beyond the ramps's freeway terminus.   It can also be characterized as having high speed-differentials at the merge/diverge, which will result in excessive braking and high acceleration noise.

General Considerations:

Left-hand ramps have often been used in an attempt to reduce right-of-way requirements and at system interchanges to reduce the number of structures from that which would be required with a semi-direct ramp. At service interchanges in particular, the use of left-hand ramps is often associated with retaining walls and restricted geometrics. These conditions affect speed-change lane design and operation, as discussed in the separate summary sheet on speed-change lanes.

1.3.1, 1.3.2, 1.3.3: Ramp Proper - Limiting Design Elements - Horizontal, Vertical, and Cross Section

Description of Cause:

Certain types of mobility problems may arise if the design of the ramp proper is too restrictive.   Designs that use minimum values (or less than minimum) for elements of the horizontal alignment, vertical alignment, and cross section are more likely to experience operational inefficiencies and safety difficulties. The problems tend to be concentrated in and around these points of minimum design. These operational and safety issues may occur at any time of the day.

The following indicators can be used to determine if the problem is one of limited design of the ramp proper:

- Sudden or severe braking due to restrictive curvature on an exit ramp.

- Deceleration on the mainline by exiting vehicles due to sharp curvature on the ramp and not enough room to adjust speed.

- Large speed diierential [> 10 mi/h (16.1 km/h)] between through traffic and entering vehicles caused by restrictive horizontal alignment or steep grades on ramp.

- Entering traffic takes path directly into through lanes due to sharp curvature on entrance ramp.

- Long queues of traffic on an exit ramp due to inadequate number or use of lanes on ramp proper.

- Conflicts or accidents due to inability of drivers to see road and traffic conditions ahead. Sight obstructions in the cross section or the profile of the ramp may not provide adequate sight distance.

- Steep upgrade conditions on a ramp result in low operating speeds for heavy vehicles. Or steep downgrades create speed control problems for the heavy vehicles.

- Instability of high profile vehicles or loss of control by vehicles due to inadequate super-elevation for operating speeds.

- Delays due to disabled vehicles on narrow one-lane ramps.

General Considerations:

Especially on older facilities, the values used for design at the time it was built are often inadequate according to current guidelines. Ramp designs should be based upon the needs of the drivers and vehicle types expected to use them. Economics alone should not be the sole reason for electing not to upgrade to more modem standards. The availability of ROW and the impact on surrounding land uses if changes to alignment or cross section are made need to be assessed. Drainage, clear zone requirements, and signing changes may be needed if the cross section is increased. The time for completion of the project, the traffic control plan during construction, and project costs are important factors, too.

1.3.4: Ramp Proper - Demand Too Large

Description of Cause:

Usually the cause of congestion on a ramp is due to the design or controls of its terminals. The capacity of the ramp roadway itself is very rarely the factor that dictates a design. In some cases though, the volume of traffic wanting to use the ramp exceeds its capacity. Problems related to large demands are found during the peak hours of the day.

The following indicators can be used to determine if the problem is one of too large of a demand for the ramp proper:

- Ramp volumes in excess of 1500 vehicles per hour on single-lane ramps other than loops. A loop ramp can generally accommodate about 800 to 1,200 veh/h.

- Queues or slow moving ramp traffic on the ramp proper.

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- Unauthorized use of shoulders on the ramp where drivers try to form two lanes when, in fact, the traveled way width can handle only one lane.

- Long queues of traffic on an exit ramp due to inadequate number or use of lanes on ramp proper.

General Considerations:

Problems of too much demand on the ramp proper are usually resolved by adding additional ramp lanes or changing their designated use. An alternative is to decrease demand to a point where an acceptable level of service will result. Many times congestion on the ramp proper is caused by the inability of the cross road intersection to serve the demand. Therefore, an investigation of the cross road terminal is often needed too.

1.4.1: General Interchange - Bask Conflguratlon Not Appropriate

Description of Cause:

There are situations that occur either because of the intersecting or adjacent facilities or the pattern of traffic volumes for which certain interchange configurations are inappropriate. The result can be an inefficient and unacceptable operation, which can be identified by such operational measures as:

- Slowing and braking on the mainline due to influences other than traffic congestion.

- Operating speeds and capacities that are below what is normally expected for comparably classed facilities.

General Considerations:

The AASHTO policy on geometric design of highways (AASHTO Green Book) provides guidelines on the appropriate wnfgurations to be employed. Examples of configurations that may, under some conditions, be inappropriate Include:

- Use of a loop ramp in a system interchange.

- Use of back-to-back loops with weaving between them occurring contiguously with the mainline flow.

- Allowing direct access from an adjacent land use to a ramp proper.

- Use of left-hand ramps.

- Use of ramps on which one terminus is controlled, but flow conditions suggest the need for free-flow or high capacity operation.

- Use of two points of exit.

- Improper placement of points of exit (e.g., beyond structure or crest of vertical curve).

- Use of two-way frontage roads to which ramps connect.

1.4.2 - **General Interchange** - Route Continulty Violated

<u>Description of Cause</u>:

Route continuity is violated when the driver on the mainline of a freeway is required to exit the facility in order to continue to follow the route designation or name of a freeway.

<u>General Considerations</u>:

Desirably, the through driver, especially the unfamiliar driver, should be provided a continuous through route on which it is not necessary to change lanes and that vehicle's operation can occur on the left of all other traffic.

Route continuity is part of the provision of operational uniformity. Its violation often occurs when there is an incomplete network and routes must be overlapped for a portion of their length. The usual form in which the violation takes place is when the major route is treated as an exiting roadway in a system interchange, rather than being given through status in the configuration. This is particularly a problem in urban areas and along city bypasses. Interchange configurations should favor the through route, even though the other movements may have greater volumes.

Advance directional signing is not generally effective for the unfamiliar driver. Sign content is often the first information shed when there is an overload because of the primacy . associated with other information processing required to maintain the vehicle in safe operation along a section of roadway that experiences complete maneuvers.

1.4.3: **General Interchange - Slippery Pavement Surface**

<u>Description of Cause</u>:

Slippery pavement surface conditions can result in mobility problems as drivers becoming more cautious. The largest effect is usually seen during periods when the surface

is wet or icy. Drivers slowdown to maintain control over their vehicles thereby reducing the ability of the roadway to move traffic efficiently.

The following indicators can be used to determine if the mobility problems are caused by slippery pavement surface conditions:

- A high number of single vehicle run-off-the-road accidents. These would normally be concentrated in sections with horizontal curves but could occur anywhere.

- Observations of difficulty for drivers to maintain control over their vehicles when the surface is wet.

- Pavement surface tests reveal a low skid number rating. An exact threshold number has not been determined. Some studies indicate that skid numbers at 40 mi/h (64.4 km/h) less than 30 represent locations where wet pavement accident rates are likely to be higher.

- Water ponding on the pavement that creates a potential for hydroplaning especially near flat points in the profile (sag vertical curves).

- Evidence of high pavement wear or poor pavement surface conditions. Examples include bleeding asphalt surfaces or polished concrete surfaces that result in less pavement surface friction available.

General Considerations:

In some climates, the occurrence of slippery pavement surfaces may be more prevalent during certain times of year. Also, in warm weather, the skid resistance properties of the tires may change too.

1.4.4: General Interchange - Poor Pavement Condition

Description of Cause:

Poor pavement surface conditions can result in mobility problems as drivers becoming more cautious. Some drivers slow down to maintain control over their vehicles thereby reducing the ability of the roadway to move traffic efficiently. Others will shift away from areas in poor condition that can result in unequal lane utilization and also increase friction with adjacent lanes. Speed reduction and lateral movement may also lead to accidents and conflicts.

The following indicators can be used to determine if the mobility problems are caused by poor pavement surface conditions:

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- A visual inspection of the surface reveals one or more of the following conditions: rutting, faulting, potholes, uneven longitudinal joints at the edge of lanes or shoulders, edge of pavement drop-off, poor shoulder condition, evidence of drainage problems such as water "pumping" at joint lines, and alligator or transverse cracking.

- An automated ride rating using an instrumented vehicle that indicates poor ride quality. The testing method used and minimum performance levels vary by agency.

- Observations of difficulty for drivers to maintain control over their vehicles in areas of rough pavement Excessive lane changing or braking may suggest poor pavement conditions too.

- Concentrations of rear-end or lane-change accidents that correspond to locations with pavement surface problems.

General Considerations:

Proper maintenance is essential to the safe and efficient operation of highways and streets. Pavement deficiencies can be identified through a Pavement Management System. This procedure usually involves a visual inspection and rating of pavement surface conditions. In addition, a ride score is ascertained using an instrumented vehicle that rates the quality or smoothness of the ride. These two ratings are then used to identify the magnitude of pavement surface problems and prioritize locations for needed maintenance. A poor pavement surface is often the result of poor subsurface conditions or might suggest improper construction practice.

1.4.5 - General Interchange - Lack of Traffic Enforcement

Description of Cause:

Violations that cause operational problems may occur in a variety of forms, but are often associated with a traffic management strategy. Should the rate of violation become high enough, significant impact on traffic operations can occur throughout the corridor.

General Conditions:

Law enforcement agencies are generally dealing with demands for service that are well beyond their capacity. Furthermore, some agencies can be unaware of the special traffic enforcement needs for facilitating corridor operation. Criminal justice matters generally take precedence in local agency operations. State highway patrols, on the other hand, have traffic enforcement as their primary objective.

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Included among general violations potentially affecting traffic operations are:

- Reckless driving.
- Hazardous driving.
- Truck size.
- Truck weight.
- Truck and other vehicle land restrictions.
- Illegally stopped vehicles {shoulder, mainline, or both).
- Use of the freeway by prohibited.

Traffic violations associated with traffic management strategies include:

- HOV lane.
- HOV bypass.
- Ramp metering.
- Lane usage and lane line crossing control.

1.4.6: General Interchange - Inadequate Lighting

Description of Cause:

Drivers need to be provided with a dear view of road and traffic conditions. At night, critical areas (intersections, interchanges, etc.) that require drivers to make decisions (sometimes complex) need to be lighted. Other areas may indicate a need for lighting if the alignment is unclear. If drivers are unsure of what they are required to do, operations are generally less efficient than if good guidance is given. Accident or conflicts can also result if the roadway lighting is not adequate.

The following indicators can be used to determine if the mobility problems are caused by inadequate lighting:

- A high frequency or concentration of nighttime accidents suggests a need for additional lighting. A minimum number of night accidents plus a certain volume of traffic that may justify lighting are specified by some agencies. These numerical values vary by type of facility (freeway, conventional, etc.) and by agency. Most computerized accident record systems should generate listings' of locations with a high level of night accidents.

- Observations of unusual driver behavior such as erratic maneuvers, apparent hesitancy or confusion, sudden braking or lane changing, etc. can be signs of a need for improved lighting.

- Visual or subjective evaluations at night can identify possible problem areas.

- Measurements can be made in the field with a light meter and compared with recommended values.

When a decision is made to provide lighting, both the quantity and quality of illumination need to be addressed. Normal practice suggests minimum values for both measures depending upon the type of roadway. Manufacturers' photometric data for different luminaries and mounting heights, initial cost, useful life, operating and maintenance costs, and replacement costs need to be considered. Cost savings due to the potential reduction in night accidents should also be included in the analysis. Reference 1 provides information on the safety benefits of lighting.

1.4.7: General Interchange - Incompatible Vehicle Mix

Description of Cause:

Most freeway truck accidents occur at interchange areas, including ramp, diverge, and merge areas. The presence of large trucks operating within interchanges and on the mainline can have a dramatic effect on operation under certain conditions. The operational impact may result from the effect of grade, curvature, and super-elevation on the truck. If there are a sufficient number of trucks operating in an unrestricted manner, just the space taken by the vehicles will reduce the vehicular flow.

General Considerations:

Conflicts between heavy vehicles and passenger cars have historically been a problem. As truck and bus size and weight allowances are increased, the problem has been exacerbated. The growth in the number of heavy trucks operating in urban areas has also contributed to the concern.

The heavy vehicle is usually traveling at speeds of 5 to 10 mi/h (8 to 16.1 km/h) slower than passenger vehicles. The higher average passenger car speeds present in the left-most lanes under unrestrained conditions indicate that heavy truck presence there will have the greatest impact. When a sufficient number of these vehicles are traveling along a corridor, they can effectively create a moving blockage, behind which queues will form whose density approaches capacity, increasing the probability of operational breakdown. If long and/or steep grades are present, the speed differentials are increased, creating further in-stream friction. Furthermore, if the Interchange or roadway geometries are restrictive, the larger and heavier vehicles can easily approach instability. This is often the cause of freeway incidents in urban areas.

2.1.1: Freeway Mainline - Steep Vertical Grade

Description of Cause:

Operations on the freeway mainline may be severely impacted by steep grade conditions. On an upgrade, single unit trucks, semi-trailers, and buses are often forced to reduce their speed. This slow down causes a speed differential and passenger cars try to shift to other lanes so as not to be affected by the slower moving traffic. Platoons may form and large gaps will be present in front of the slow moving vehicle. Inefficient utilization of lanes result and when coupled with the lower speeds, this degrades the quality of operations. On downgrades, speed control is the major concern for the heavy vehicle types. Safety problems may arise due to speed differentials and/or loss of control on steep grades. Operations at ramp junctions located on steep vertical grades may also be adversely affected.

The following indicators can be used to determine if the mobility problem is due to steep vertical grades:

- Heavy vehicles are required to reduce their speed on an upgrade by 10 mi/h (16.1 km/h) or more. References 1 and 2 provide insights regarding what combination of percent and length of grade would result in various speed decreases.

- Observations of traffic shifting to lanes that are not typically used by the heavy vehicles.

- Large gaps form in front of heavy vehicles traveling on the upgrade.

- Shoulder riding by vehicles affected by the upgrade.

- Excessive braking on either up- or downgrades as faster vehicles wme upon slower moving ones.

- Ramp traffic on upgrades entering at substantially lower speed than mainline traffic. Ease of entry is dictated primarily by amount and spacing of heavy vehicle traffic in the outside lane.

- Rear-end and lane-change accidents on either the up- or downgrade.

General Considerations:

The design of the vertical alignment often represents a compromise among safety, earthwork, environmental/aesthetic considerations, and cost. It is neither practical nor desirable to provide grades that are nearly level at all locations. A gentle vertical profile (grades less than 1 - or 2-percent) can be aesthetically pleasing while not significantly affecting operations. Care should be exercised in coordinating the features of the horizontal and

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vertical alignment to provide adequate sight distance, good drainage, and to avoid violation of driver expectancy.

2.1.2: Freeway Mainline - Inadequate Vertical Curve

Description of Cause:

Smooth gradual transitions between tangent grade lines are accomplished with sag and crest vertical cuwes. The design should provide appropriate sight distance, good drainage, comfortable operation, and a natural, pleasing appearance. If the curve is not designed properly, operations and safety can be negatively influenced. Abrupt changes in grade may cause drivers to slow suddenly. A view of the road that is hidden by a crest curve can cause uncertainty in drivers and cause them to slow or brake near the top of the hill. Rear-end, lane change, and fixed object accidents may be due to restricted visibility and violation of driver expectancy. If the road does not drain properly near a sag curve, water can pond and vehicles may experience hydroplaning or may slow suddenly.

The following indicators can be used to determine if the mobility problem is due to an inadequate vertical curve:

- Sudden slowing or braking by drivers approaching a crest in the road profile.

- Limited visibility at crest vertical cuwes as evidenced by rear-end, lane change, or fixed object accidents.

- Water pending in the lanes near the low point of a sag vertical curve. There may be a history of wet pavement or loss of control accidents.

- A generally unpleasant appearance of the profile. The roadway alignment does not appear to flow well or smoothly.

- Uncomfortable ride when going over a crest or through a sag curve traveling at the typical operating speed of traffic.

General Considerations:

The criteria for vertical cuwes are based on accomplishing a safe and smooth transition between tangent grade lines. K-values, representing the rate of change of the vertical alignment, are specified by AASHTO to provide absolute minimum and desirable minimum sight distances. It is certainly acceptable to use higher K-values that result in longer curves. This is especially true for sag cuwes where use of the minimums can cause an unsightly appearance. The design of the vertical alignment often represents a compromise among safety, earthwork, environmental/aesthetic considerations, and cost. Care should be exercised in coordinating features of the horizontal and vertical alignment to provide adequate sight distance, good drainage, and to avoid violation of driver expectancy.

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2.2.1.1: Freeway Mainline - Insufficient Number of Lanes (Basic or Auxiliary)

Description of Cause:

An insufficient number of lanes on the freeway mainline results when the demand volume exceeds the capacity of the section. It is a recurrent problem usually seen during the peak hours on weekdays. The pattern and effects of congestion that result may be seen for some time before and after the typical peak hours. The most visible effect, mainline queuing, may be evident for miles.

The following indicators can be used to determine if the problem is one of insufficient number of lanes:

- Stop and start operations with queues building and/or standing in the mainline lanes with small disturbances resulting in breakdown.

- Low operating speeds, usually around 30 mi/h (43.3 km/h).

- Uniform headways, but short gaps [80 ft (24.4 m)] and limited ability to change lanes, which may cause delays in ramp merge areas.

- Unauthorized shoulder riding by through and/or ramp vehicles.

- Diversion to surface streets to bypass congestion.

- Congestion at or upstream of lane drops.

General Considerations:

The availability of ROW and the impact on surrounding land uses if lanes are added on the inside or outside of the alignment need to be determined. The drainage and dear zone requirements and signing changes needed if the cross section is increased should be studied. The length and location of the added lane has to be coordinated with adjacent interchanges to provide lane balance. If the required number of mainline lanes exceeds eight, a dual roadway system should be considered. The time for completion of the project, plus the traffic control plan during construction and costs, are important factors too. Also, the extent that the future volume estimates reflect the use and effects of travel demand management strategies should be determined.

2.2.12: Horizontal Element - Lanes - Dropped/Added

<u>Description Of Cause</u>:

The addition or reduction of a lane from a freeway can have widely differing effects on the operation, depending upon how it is handled. The result can be poor operation due to incomplete use of the capacity of the lane, or erratic maneuvers, braking, and lane changing associated with it.

<u>General Considerations</u>:

Factors of interest include location and design. Lane drops may occur in such a manner that they violate driver expectancy or their termination is not seen sufficiently in advance. If an auxiliary lane is added prior to an exit to provide additional capacity for the ramp, the lane must be of sufficient length to allow vehicles to move into it and fully utilize it. Lane additions from an entrance ramp must also be of sufficient length to allow vehicles to move out of it at a rate more like normal lane changing than a merge.

2.2.1.3: Horizontal Element - Lanes - Continuity

<u>Description of Cause</u>:

It is possible to have a condition where there are one or no lanes on which the through driver may place the vehicle and remain throughout the corridor. This condition results in unnecessary lane changing by through traffic and violates driver expectancies, possibly causing erratic maneuvers.

<u>General Considerations</u>:

The condition described above can result when lanes are added and deleted along the corridor on both sides of the facility and lane balance requirements are not observed. If there are three or more lanes on the facility, it may occur that both the left and right lanes are dropped and added through interchanges and/or mainline lane additions and deletions. If lane balance is not obsewed, then single lane exits at which a lane is dropped can result in a through lane being terminated.

22.1.4: Freeway Mainline - Lane Balance Violated

<u>Description of Cause</u>:

Lane balance at an interchange is violated when the number of lanes on the mainline does not correspond well with the number of ramp lanes. This balance between the number of basic and auxiliary lanes on the freeway and ramps helps to reinforce driver expectancy. The problems that result because of a lack of lane balance can occur at any time. The most obvious obsewabie effects are erratic maneuvers made by ramp or mainline vehicles upstream, downstream, or in the merge or diverge area

The following indicators can be used to determine if the problem is a lack of lane balance:

- Erratic maneuvers in the merge or diverge area, such as abrupt or excessive lane changes, encroachments into the gore, shoulder, or median.

- Through traffic shifting away from the potential disturbance in the merge or diverge area This can occur well upstream of the ramp.

- Lane change, sideswipe, fixed object, rear-end accidents, and conflicts.

- Unclear lane pavement markings or guide signs.

- Inconsistent number or arrangement of through or ramp lanes, such as an exit only lane at a diverge.

<u>General Considerations</u>:

The following principles of lane balance should be obsewed:

- At entrances, the number of lanes beyond the merge should not be less than the sum of all lanes on the merging roads minus one.

- At exits, there shouid be one more lane going away from the diverge than was approaching it. Exceptions are cloverleaf ramps and successive entrance and exits separated by less than 1,500 and connected with a continuous auxiliary lane.

- The mainline should not be reduced by more than one lane at a time.

The availability of ROW and the impact on surrounding land uses should be determined if additional lanes are needed. The impact on clear zone requirements and drainage should be addressed, too. The length of an added auxiliary lane should be coordinated with adjacent interchanges. Special effort should be made to provide a uniform pattern of entrance and exit ramps, especially where interchange spacing is short Changes

in signing and marking are needed if the cross section is to be changed. The time for completion of the project, plus the traffic control plan during construction and costs, are important factors, too.

2.2.2: Freeway Mainline - Horizontal Curve/Super-Elevation

Description of Cause:

If a horizontal curve is too sharp for the prevailing speed and super-elevation provided, drivers will have difficulty controlling the vehicle. A flattening of the path, with possible encroachment on adjacent lanes, and/or a reduction in speed are the probable responses by the driver. Either of these actions can result in inferior operations and potentially hazardous circumstances.

The following indicators can be used to determine if the mobility problem is due to an inadequate vertical curve:

- Physical evidence of vehicle control problems in the vicinity of the curve, such as yaw marks on the pavement or shoulder. There also may be signs of vehicles running off the road entirely.

- Concentrations of single-vehide run-off-road accidents, typically to the outside of the curve. In some cases, maintenance records may show evidence of run-off-road problems that do not show up in the accident record data base (sign knockdowns, guardrail hits, etc.). A high number of wet or slippery pavement accidents may also be a sign of some problem with the curve itself. Although not as common, there may be some sideswipe accidents, too.

- Obsewations of drivers trying to -flatten the curve.' They try to minimize speed reduction by following a flatter path through the curve than is actually provided, encroaching on adjacent lanes.

- Lane encroachment may occur prior to the actual point of curvature and beyond the end of the curve if no transition, or spiral, curve is Induded.

- Poor delineation of the roadway alignment.

General Considerations:

Drivers expect to be able to maintain a constant speed unless informed otherwise. The alignment should provide for a consistent operating speed throughout its length. Points of minimum design tend to be where operational and safety problems are concentrated. AASHTO provides guidelines for combinations of super-elevation, side friction, and radius of curve for various design speeds

3.1: Highway System - Missing Links

Description of Cause:-

       If a planned section of the highway network has not been built, the lack of system continuity may result in a distortion of travel patterns from those on which system capacity was based. As a result, other corridors experience traffic overloads.

General Considerations:

       Sections of the highway network may remain unbuilt either because of lack of funding, or because it has been found infeasible to build in the corridor. The former involves economic and programming issues, while the latter primarily involves environmental and political issues. It is difficult to predict the distortion in patterns that will occur when a link is missing, but regional traffic assignment models can provide information concerning the extent to which an existing corridor would be relieved by the provision of the missing link. It cannot be assumed that the traffic that would have otherwise been sewed by a continuous parallel facility will affect only those corridors immediately adjacent, and parallel, to the corridor. The diverted trips may follow a zig-zag pattern through the system, utilizing sections of many different corridors.

3.2: Highway System - Lack of Parallel Capacity

Description Of Cause:

       A corridor may experience regular traffic overloads because it attracts trips from too broad a service area. The vehicles may travel some distance to access the corridor because they find no other more attractive facilities to serve the trips.

General Considerations:

       Insufficient capacity to handle demands parallel to the corridor under study may result from too low a density of freeway and/or arterial facilities, or an orientation of existing facilities toward serving other travel patterns. Demand patterns may have developed differently from those anticipated when the existing facilities were constructed. This may be caused by land uses and densities occurring in different configurations than projected. The problem may also develop when the freeway system development process has been stalled or stopped -- often from lack of funding or for reasons of public policy.

3.3: Highway System   Overlap of Routes

<u>Description of Cause</u>:

When two major highway route designations are assigned to facilities that are generally separate, but overlap even for a relatively short length in an urban area, it often results in major operational problems because of the volume overloads and intense weaving action that occurs. Capacity may be reached at the points of interchange between the two routes, or along the section of overlap.

<u>General Considerations</u>:

Route overlap can occur, for example, where there are physical constraints, radial facilities focusing upon a major central business district, where inadequate funding is available to provide a parallel facility, or when public policy dictates. Several of these can cause the network to have missing links.

Overlapping route designations do not always create a problem. There are many cases where the multiple designation of a facility is for convenience through an urban area and the route designations serve the same basic corridor demands.

Route continuity violations often occur at the interchanges between the two overlapping facilities. However, in this case, a mere change of route designation will generally not deal with the underlying problem of two heavily traveled movements being forced to share the same traveled way.